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1983

New Hampshire Water Supply and
Pollution Control Commission, Concord

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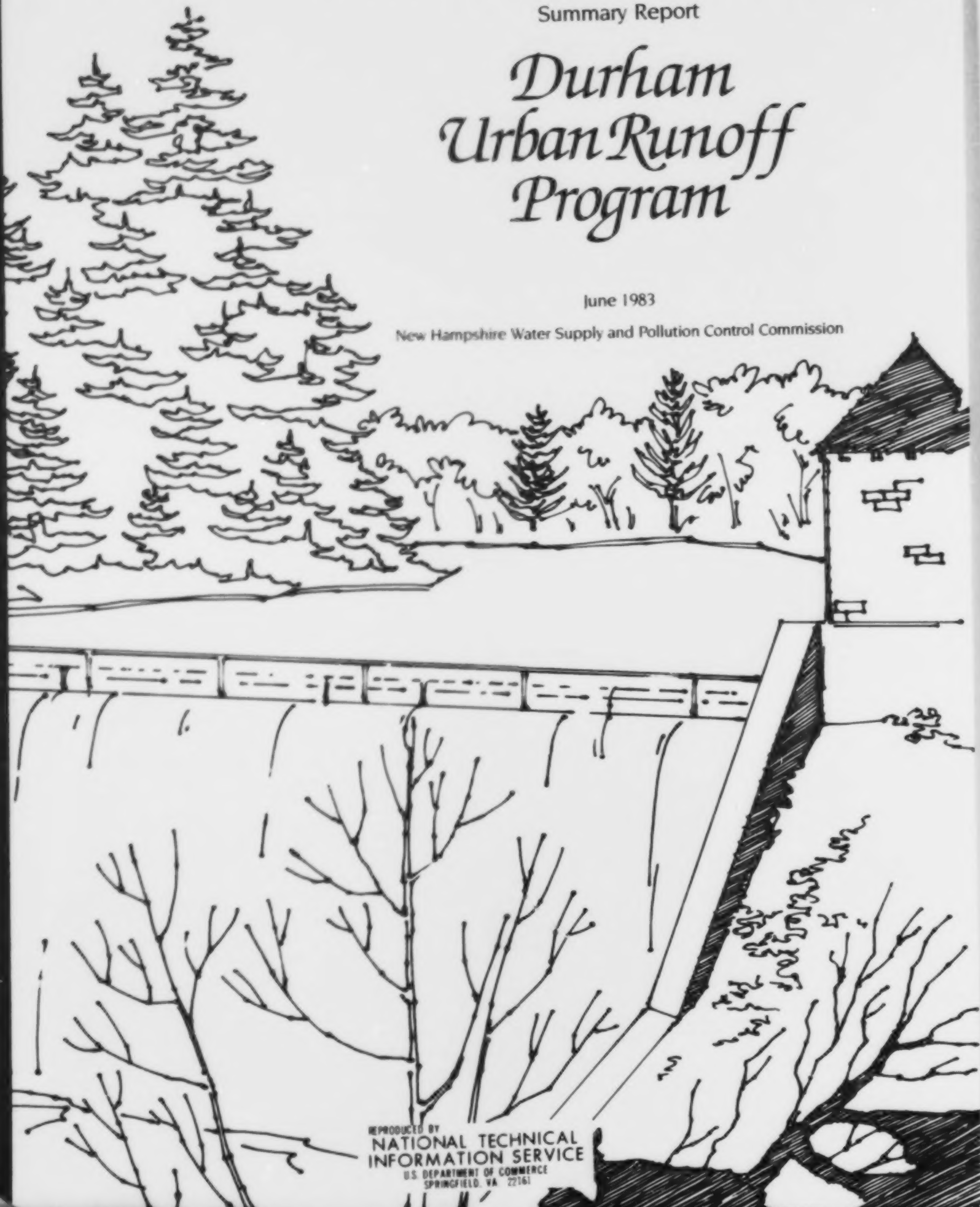
Summary Report

Durham Urban Runoff Program

June 1983

New Hampshire Water Supply and Pollution Control Commission



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December 28, 1983

Mr. William A. Healy, P. E.
Executive Director
Water Supply & Pollution Control Commission
Hazen Drive
Concord, New Hampshire 03301

Dear Mr. Healy:

Transmitted herewith is the summary report of the "Durham Urban Runoff Program."

This study was designed to document water quality impacts of stormwater runoff from various land use types in the Durham area, and to relate these impacts to possible violations of state water quality standards. Additionally, several control measures were evaluated in terms of stormwater runoff contaminant removal efficacy. Recommendations are presented for the control of stormwater runoff impacts in the study area.

Study findings will add significantly to the data base already accumulated by the Commission with respect to urban runoff phenomena. Extension of this information will enable recommendations for urban runoff control measures statewide.

This study was funded in part by the Environmental Protection Agency in conjunction with the Nationwide Urban Runoff Program.

Respectfully submitted,

Paul H. Oakland

Paul H. Oakland
Aquatic Biologist

PHO/vv
Enclosure

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This project was conducted in 2 phases, an assessment of runoff conditions, and implementation and evaluation of control measures. Phase 1 objectives:

Measuring urban runoff constituent mass loadings for individual events and their relationships to storm characteristics, and between 3 different subcatchments;

Measuring receiving fresh water impacts, possible WQ standards violations, and implications;

Modelling runoff impacts on estuary receiving water, possible WQ standards violations, and implications.

Phase 2 objectives:

Evaluation of effectiveness of urban runoff control measures between 3 differing subcatchments, measure impact on freshwater receiving stream, and model the impact on estuary receiving water, of the control measures.

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SUMMARY REPORT

DURHAM URBAN RUNOFF PROGRAM

SR 136

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Robert A. Cruess, P. E.
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Paul L. Heirtzler, P. E.

Report sections I.1 through I.3, which describe the study area, and the Literature Review (Appendix D), were written by Lisa Eggleston while under contract to the New Hampshire Water Supply and Pollution Control Commission. Charlie Vorosmarty is the principal author of Section III - "Oyster River Estuary Computer Model Applications," which was also produced contractually. Minor modifications were necessary in both cases to provide continuity with the summary report.

During my tenure as Program Manager, the enormous staff resources available at the New Hampshire Water Supply & Pollution Control Commission proved to be an invaluable asset. By tapping into these resources, my limitations were overcome and positive addition to the program resulted. To avoid possible oversight, my gratitude and compliments are extended to all staff members who supported this program.

Several individuals deserve special mention:

Kathy Barlow for editorial input, assistance with public participation aspects of the program, field data acquisition, and data analysis.

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INTRODUCTION

The New Hampshire Water Supply and Pollution Control Commission, with Nationwide Urban Runoff Program funding assistance, has investigated the impacts and methods for control of stormwater runoff within the lower Oyster River Basin in Durham, New Hampshire. The study was conducted in two phases, the first phase being an assessment of existing runoff conditions, and the second involving implementation and evaluation of control measures. Specific study objectives were as follows:

Phase I - Base Line Study

1. Measure mass loadings of urban runoff constituents during individual storm events and relate these loadings to the storm characteristics.
2. Compare and relate the mass loadings of urban runoff constituents between three subcatchments differing in hydrogeological and land use characteristics.
3. Measure the impact of urban runoff upon the freshwater receiving stream and relate this impact to possible violations of State Water Quality Standards and its implications.
4. Model the impact of urban runoff upon the estuary receiving stream and relate this impact to possible violations of State Water Quality Standards and its implications.

Phase II - Control Measures Study

1. Measure the effectiveness of urban runoff degradation control measures in terms of mass loading reduction and as a function of storm characteristics.
2. Compare the effectiveness of urban runoff degradation con-

trol measures between three subcatchments differing in hydrogeological and land use characteristics.

3. Assess the impact of urban runoff degradation control measures upon the freshwater receiving stream and its State Water Quality Standards classification.
4. Model the impact of urban runoff degradation control measures upon the estuary receiving stream and its State Water Quality Standards classification.

In addition to these primary objectives, study results will be incorporated into the data base already accumulated by the Water Supply and Pollution Control Commission with respect to stormwater runoff phenomena. Extension of this information will enable recommendations for control measures in other parts of the State where stormwater runoff is a problem.

This report summarizes program efforts and analytical results of data collected throughout the Durham Urban Runoff Project, encompassing the period May 1980 through November 1982.

BACKGROUND

Several factors were involved in selection of the Oyster River Basin as the study site. Primarily, Durham's rapid growth rate is considered representative of that occurring in much of southern New Hampshire. Therefore, data generated would have broad applicability.

Resource impairment of the Oyster River Estuary was also a major factor in study site selection. The Oyster River Estuary, once considered a significant shellfishery resource, is threatened by episodic water quality degradation. With the implementation of appropriate upstream control measures, it may be possible to reduce water quality impacts associated with significant rainfall events, thus restoring a potentially viable shellfishery resource.

In addition, computer modeling of water quality in the Estuary just below the study area was already underway by the Sea Grant Estuarine Modeling Group at the University of New Hampshire, located in Durham. It was felt that the two programs would complement each other in order to develop a planning methodology to assess water quality impacts of coastal zone development.

Also, the Town of Durham expressed interest in improving and protecting water resources in the area, and offered to cooperate in the conduct of the study program. Cost-effective stormwater runoff control measures recommended as a result of this study will be considered for implementation in Durham.

SUMMARY AND CONCLUSIONS

Section I - Base Line Study

In order to achieve the objectives of study Phase I, the tidal estuary, two freshwater streams (Pettee Bk., Oyster R.), and an urban parking lot within the Oyster River drainage basin were selected for study. Each subcatchment receives significant stormwater runoff from urbanized areas in Durham.

On the basis of extensive field sampling during study Phase I, water quality has been shown to significantly decline as a result of stormwater runoff in the Durham area. Water quality problems are manifested in widespread in-stream violations of New Hampshire turbidity and total coliform bacteria standards. In addition, heavy metals in parking lot runoff are shown to pose a potentially serious threat to receiving water quality. Stormwater runoff impacts affect the tidal estuary as well as freshwater receiving streams.

Turbidity

Turbidity samples collected from freshwater streams during storm runoff periods show routine violations in Pettee Brook and less frequent violations in the Oyster River. Only minor differences between upstream (background) and downstream stations are indicated. These results suggest stormwater runoff from the urbanized areas are not significantly more turbid than runoff from rural areas in Durham. Turbidity violations likely result from erosion of exposed soils, street dirt washoff, and stream bank erosion associated with high stormwater runoff flows.

Coliform Bacteria

Coliform bacteria violations were encountered during base flow periods in both freshwater streams and the tidal estuary, but are not nearly as

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severe or as frequent as with storm runoff conditions. The possibility of an occasional sanitary discharge exists which may be responsible for the observed dry weather violations. However, since the Town of Durham maintains a separate sanitary and stormwater sewer system, human sources are not suspect in the tremendously increased violations associated with storm flows. More likely, a substantial portion of coliform bacteria contamination is contributed by surface washoff of animal feces.

Heavy Metals

Results for parking lot runoff show frequent heavy metal standards violations, with concentrations of zinc and copper reaching acute toxicity levels. Observed criteria violations, coupled with a statistical analysis of violation recurrence intervals, suggest stormwater zinc and copper concentrations reach "end of pipe" toxic levels with regularity. High metal concentrations in parking lot runoff have been shown to correlate well with the low rainfall pH levels experienced throughout this study.

Overall, metals concentrations were low in both the Oyster River and Pettee Brook. Although marked increases in stormwater over base flow were observed, concentrations high enough to result in acute toxicity were rarely encountered.

Findings of the Phase I - base line study reveal denial of potential beneficial uses of freshwater streams resulting from stormwater runoff in Durham. These uses include water contact recreation, and perhaps the ability to support aquatic life which are sensitive to intermittent exposure to high heavy metals and/or turbidity levels. However, swimming generally does not occur during periods of wet weather, and physical conditions in nearly all freshwater surface areas preclude contact recreation. In addition, state fishery management goals are being attained in the area. For these reasons, existing uses of Durham's freshwater resources are not obviously impaired as a result of stormwater runoff in the area.

As with the freshwater streams, contact recreation in the Oyster River estuary likely does not occur during wet periods, and fishery management goals are being attained. However, coliform bacteria concentrations well in excess of the legislated quality for shellfish harvesting waters are frequently encountered in the estuary. This condition results in denial of an otherwise viable shellfishery in the estuary.

Section II - Control Evaluations

Section II deals with evaluation of stormwater runoff degradation control measures. Three control methods were evaluated, two at the parking lot site (grassed swale treatment and pavement vacuum cleaning), and another in the freshwater Oyster River catchment (river-run impoundment). Summaries and conclusions drawn from each of these control evaluations are discussed below.

Grassed Swale Treatment

Following guidance presented by the U. S. Soil Conservation Service, a parabolic vegetated waterway (swale) has been evaluated in terms of stormwater runoff pollutant removal. The design criteria were based upon the requirement to reduce runoff velocities through the structure to a maximum of 2 fps. Stormwater runoff entering the swale was sealed from groundwater infiltration. Dimensions of the swale were 10' top width by 1' bottom depth, sloping at a grade of 1.5% over the 100' length. Reed-canary grass (*Phalaris arundinacea*) was used as vegetative cover.

Twelve storm events were sampled for evaluation of this control. Stormwater runoff quality was significantly improved as a result of grassed swale treatment. Removal of COD, inorganic nitrogen, total residue, and total and dissolved fractions of heavy metals were significant. Increases in pH averaged 1.42 units.

Decreases in BOD, turbidity, specific conductance , organic nitrogen, and total phosphorus were not significant, and increases in suspended residue, dissolved orthophosphate, and bacteria concentrations, were observed.

Swale removal efficiences for heavy metals are shown to improve with increased concentrations during runoff events, thus dampening peak concentrations and receiving water impacts which may result.

Changes in pH over the swale length were generally constant, with no significant differences between the upper and lower 50 feet of swale. Specific conductance increases in the lower 50 feet of swale length for runoff volumes in excess of "first flush" concentration maxima, suggest mobilization of dissolved substances from the swale substrate.

Grassed swale pollutant removal efficiency is influenced by runoff pH, and to a lesser extent, by the length of dry period between storms.

These results show that stormwater runoff diversion through grassed swales may be an effective means of reducing stormwater-borne pollutants. Since the swale structure evaluated here did not include provisions for groundwater infiltration, the observed pollutant concentration decreases are attributed to mechanisms involving plant-soil interactions.

Where groundwater infiltration is coupled with grassed swale treatment, increased removal of pollutant loads can be realized. However, where poor soil permeability or space limitations preclude stormwater infiltration areas, grassed swales may still be installed to provide for substantial pollutant reductions prior to receiving water discharge.

Dramatic increases in runoff pH resulting from grassed swale treatment are assumed active in the high removal efficiency for heavy metals. These results suggest that acid precipitation effects on receiving water quality may be reduced via grassed swale treatment, especially in urban areas where plant/soil interactions with stormwater runoff are limited.

Pavement Vacuum Cleaning

This control evaluation involved measuring the influence of pavement vacuum cleaning on stormwater runoff quality. Nine storm runoff events were sampled during a period when the entire pavement surface was cleaned daily with a vacuum machine resembling a standard size push-type lawn mower. Results of this monitoring program were then compared with runoff quality data collected during a period when vacuum cleaning did not occur.

Due to the large pollutant concentration variability common in stormwater runoff quality, nine storm events did not provide an adequate data base to gain conclusive results. However, general indications of pollutant removal performance have been provided.

Significant removal of non-filterable solid materials is shown. This result is expected, since larger particle sizes are easily removed with the vacuum cleaner, and performance is obvious when contents of the "collection bag" are examined. Results also show that dissolved solids are not removed to any significant degree from the parking lot surface. These findings tend to support the reported ineffectual removal of very small particle sizes which has been experienced in other street sweeping evaluations. Significant removal of BOD_5 and fecal streptococci bacteria suggests these materials may be associated with the larger particle sizes.

River-Run Impoundment

Mill Pond is an 8.5 acre impoundment of the freshwater Oyster River which discharges to the tidal estuary. Late summer low dissolved oxygen levels and luxuriant aquatic plant growth suggest settling of organic materials and associated plant nutrients in the pond. Evaluation of pollutant removal efficiency of this river-run impoundment has involved water quality and flow monitoring of tributary inputs to Mill Pond, as well as the outlet. Mass balance analysis has enabled quantification of pollutant removal.

Study results show considerable reduction of mass loads resulting from treatment in Mill Pond. Influent load reductions of total and fecal coliforms, NO_2+NO_3, total P, Zn, and total residue, were significant. Reductions of BOD, COD, and Pb, were also observed, but were not statistically significant. Net increases of TKN, PO_4, and Cl loads werealso not significant.

In terms of protecting the estuary shellfishing resource downstream of Mill Pond, removal of total and fecal coliforms averaging 59.6% and 52.6% (respectively) is perhaps the most beneficial impact of impoundment. Estuary water quality monitoring conducted during Phase I of this study (Section I) reveals frequent violations of coliform bacteria standards for shellfishing waters. Were it not for treatment provided in Mill Pond, estuary coliform concentrations could be substantially greater.

Correlation analysis reveals a trend of improved mass load removal efficiences associated with decreased flow rates through Mill Pond, indicating that detention time is an important factor.

Section III - Estuary Water Quality Modeling

Computer modeling was performed to estimate impacts of stormwater runoff in the Oyster River estuary. These impacts have been defined in terms of New Hampshire coliform bacteria and dissolved oxygen standards violations. Additionally, having evaluated performance efficiencies of stormwater runoff degradation control measures (Section II), results of modeling efforts were used to estimate improvements to estuary water quality resulting from control implementation.

Rigorous data requirements for verification of the detailed model were not entirely satisfied, therefore various assumptions were necessay for application of the model. Accordingly, accurate quantitative predictions of estuary water quality were not permitted. However, modeling efforts have been instructive in examining the qualitative behavior of the estuary system. Also, insight has been gained concerning system sensitivity to pollution loading.

On the basis of coliform bacteria and BOD loading rate probabilities developed from the Phase I (Section I) data base, simulations of estuary water quality changes resulting from various loading scenarios were possible. These results indicate that coliform bacteria standards for shellfishing waters are violated routinely during stormwater runoff events, especially at upriver locations. These violations are most pronounced during ebbing tides when ocean dilution influences are minimal. Coliform violations are also common at the upriver sites during periods of dry weather, but are generally not expected at downriver sites.

Results for BOD modeling suggest estuary dissolved oxygen standards could be violated during stormwater runoff conditions generated from 28% of all storms. These violations are expected to be short lived (hours) and to occur primarily at upriver locations during ebbing tides only. Estuary dissolved oxygen violations are not to be expected during periods of dry weather.

Model predictions show no impact from the Durham Wastewater Treatment Facility discharge. Model input parameters were based upon design flows and permitted concentration discharge limits for coliform bacteria and BOD.

Evaluations of stormwater runoff degradation control measures show that only river run impoundment in Mill Pond results in significant removal of coliform bacteria. Observed estuary conditions already reflect the reduced coliform concentrations resulting from treatment in Mill Pond. Results of the Mill Pond analysis suggest concentration increases up to 45% can be expected if this control were removed.

Based upon mass loading results obtained from Phase I data (Section I), runoff contributions from the impervious parking lot site account for most of the net urban catchment BOD loads. Results of control evaluations show the vacuum cleaning practice can achieve a 58% reduction in BOD loads. Performance evaluations of the other control methods did not show significant BOD removal.

Results of BOD modeling suggest that broad application of the parking lot vacuum type of control could safeguard against potential dissolved oxygen violations in the estuary.

RECOMMENDATIONS

Based upon the results of this study, and conclusions drawn, the following recommendations for improved water quality are offered:

(1) Wherever possible, paved surface drainage should be passed overland, preferably through grassed swale type areas. This method of treatment has been shown to significantly reduce stormwater runoff pollutant loads. In addition, interactions with grass and soil will protect receiving streams from extremely low runoff pH levels and related problems resulting from acid rainfall in the area.

(2) Riprap or otherwise stabilize stream banks in both Pettee Brook and College Brook to reduce turbidity levels.

(3) Remove the University swimming pool filter backwash discharge from Pettee Brook.

Coliform bacteria contamination is the most widespread and serious water quality problem encountered. Suspected controllable sources of contamination include the slight possibility of sanitary waste discharge, and surface washoff of animal feces. While control of sanitary discharge is relatively straightforward, control of animal wastes is generally difficult. The following suggestions are presented.

(4) To remove the possibility of sanitary waste contamination, inspect sanitary sewer lines and repair or replace sections where leakage is suspected, or where the potential for surcharge exists. Inspections for septic system failures should also be conducted.

(5) Substantial removal of fecal coliform has been shown in results of the parking lot vacuum study. This practice should be generally encouraged.

(6) Results of the river run impoundment study suggest detention time is critical in reducing coliform loads. Detention, or retention in percolation areas prior to surface water discharge, will aid in coliform load reductions.

(7) Use restrictions around the Durham water supply reservoir should be enforced.

(8) Elevated coliform concentrations encountered at sampling stations located upstream of urbanized areas in Durham suggest contamination from agricultural runoff. Efforts should be made to control this potential contamination source.

SECTION I

PHASE I - BASE LINE STUDY

I.1 GENERAL DESCRIPTION OF THE STUDY AREA

The Town of Durham, New Hampshire, is situated in the southeastern portion of the State, approximately twelve miles inland from the Atlantic seacoast. The Town encompasses a total land area of about 23.3 square miles. Most of Durham's development has occurred in the northern section of the Town, focused upon the campus of the University of New Hampshire. Land use there is described as institutional, with associated recreational, residential, and commercial development. Outlying areas of the Town are rural, with many open pastures and fields, but little active agricultural use. Large tracts of forested land are also common to the area, generally of the typical Northern-Hardwood-Hemlock-Spruce cover, but varying locally with soils and slope. According to 1980 census data, Durham's household population is 4,707, and the institutional population is 5,518. The latter figure represents only those students residing within Durham, as the University's total enrollment is 10,500.

Like much of New England, the topography in the Durham area consists of gently rolling hills interspersed with many small streams. These streams form the watershed of the Oyster River, which originates to the west of Durham and flows southeasterly through town and into the Great Bay Estuary. The Oyster River drainage area encompasses 30.5 square miles. Average flow of the Oyster River, as measured at the United States Geological Survey gauge on Route 4, is 47.9 cfs. The River's legislated water quality is "Class A" west of Mill Road and "Class B" east of Mill Road. The Water Quality Standards require that "Class A" waters be acceptable for public water supply after disinfection, with wastewater discharge prohibited, and that "Class B" water be acceptable for water supply after adequate treatment, with no wastewater discharge allowed

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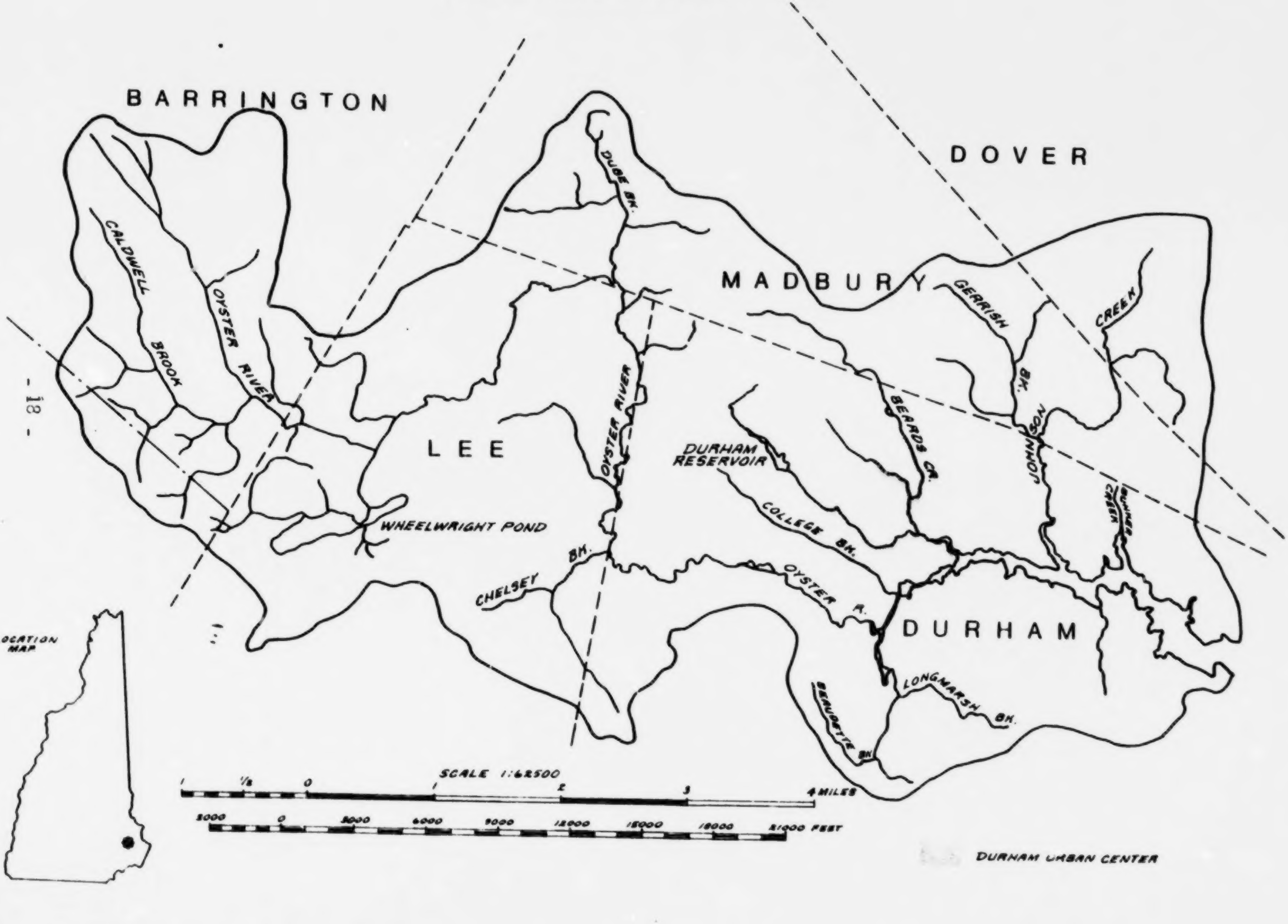
FIGURE 1

OYSTER RIVER DRAINAGE BASIN


BARRINGTON
DOVER
MADBURY
LEE
DURHAM
CALDWELL BROOK
OYSTER RIVER
DUBE BK.
OYSTER RIVER
WHEELWRIGHT POND
CHELSEY BK.
DURHAM RESERVOIR
COLLEGE BK.
BEARDS CR.
GERRISH BK.
JOHNSON CREEK
BUNKER CREEK
OYSTER R.
LONGMARSH BK.
BEAUDETTE BK.
SCALE 1:62500
1 1/2 0 1 2 3 4 MILES
3000 0 3000 6000 9000 12000 15000 18000 21000 FEET
LOCATION MAP
DURHAM URBAN CENTER

unless sufficiently treated to meet classification standards.

The surficial geology of the Durham area is the result of the last stage of glaciation in the Pleistocene Epoch, 10,000 years ago. During that time, stony, loamy glacial till and sandy-gravelly and clay glacio-fluvial deposits were laid down over the bedrock. It is the position within these deposits which determines the present characteristics of each soil type. The Oyster River Basin lies within what is referred to by soil scientists as the Hollis-Charlton-Buxton-Scantic soil association. The Hollis soils are those which form in shallow layers of till on knolls and hilltops. They are droughty and somewhat excessively drained. The well drained Charlton soils were formed on side slopes in thicker till. The Buxton soils, formed in silt and clay deposits, are moderately well to poorly drained, and are slowly permeable. In the more level areas, also formed in silt and clay deposits, are the poorly drained and slowly permeable Scantic soils.

The climate of southeastern New Hampshire is typified by warm summers and cold winters, with precipitation distributed fairly evenly throughout the year. The area generally receives its weather from inland regions to the south and west. Occasionally, however, coastal storms referred to as "northeasters" blow up the Atlantic coast, bringing heavy winds and significant amounts of rain or snowfall. The University of New Hampshire in Durham has operated a National Oceanic and Atmospheric Administration (NOAA) weather station on the premises since 1931. Data from that station indicate that the average temperature in Durham has been 47.1°F and the average annual precipitation 41.89 inches. The temperature range varies widely from winter to summer and day to night. Although precipitation, especially as snowfall, varies from year to year, the totals rarely differ more than 25 percent from normal. Statistically, precipitation of 0.1 inches or more falls an average of 83 days during the year.

I.2 SITE DESCRIPTIONS

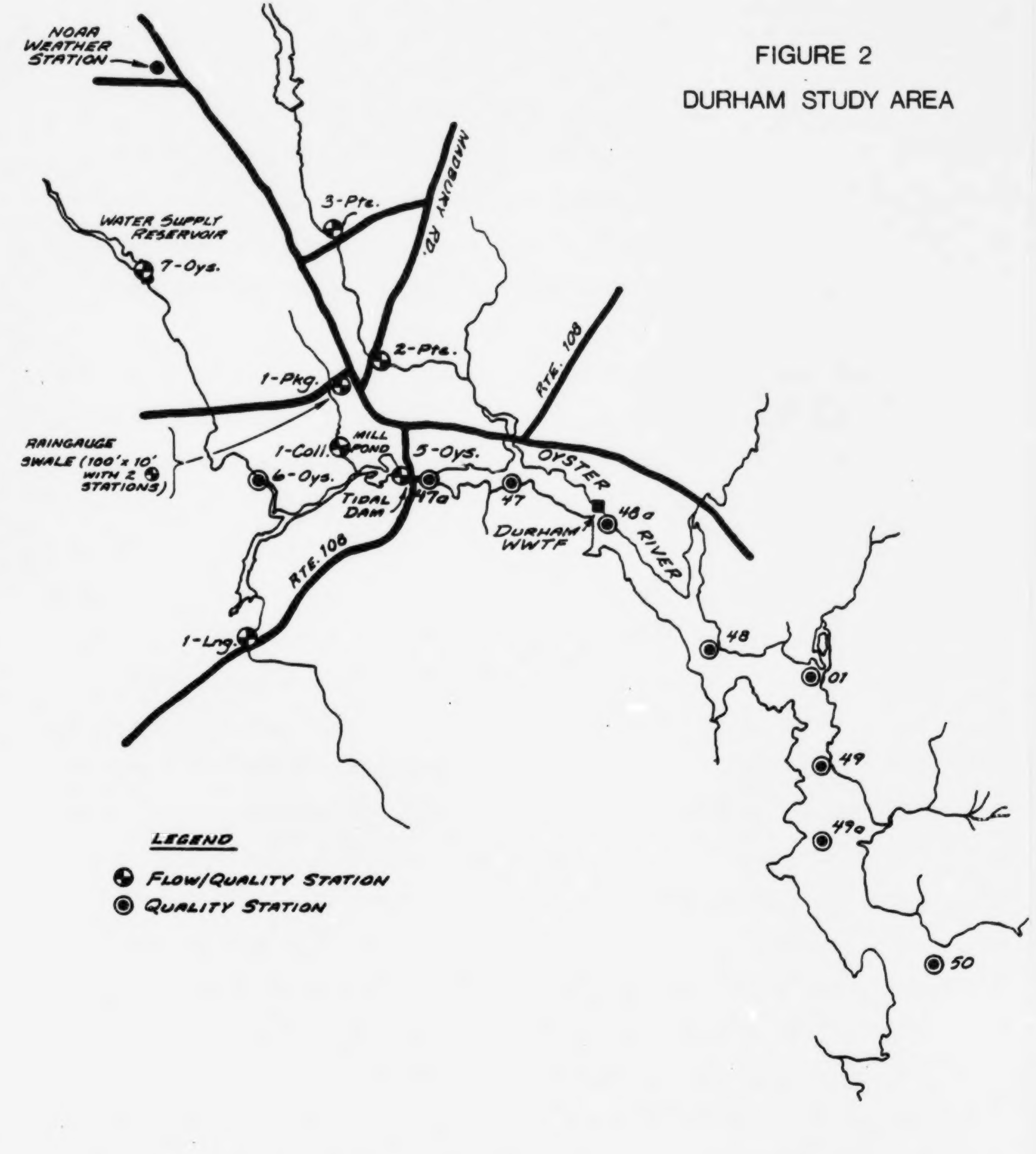
Since the sampling strategy for two of the three subcatchments selected for study involved both an upstream (background) station and a downstream test station, a total of five stormwater runoff monitoring stations were required during Phase I of this study; four in-stream stations and one end-of-pipe station.

Two in-stream monitoring stations are located on the main branch of the Oyster River. These stations, identified as 7-Oys (upstream) and 5-Oys (downstream), were established to isolate the downtown, more intensely developed area of Durham which drains to the freshwater lower reach of the Oyster River. The other two in-stream stations, identified as 3-Pte and 2-Pte (upstream and downstream, respectively), are located on Pettee Brook, a tributary to the Oyster River Estuary. These monitoring stations were selected to isolate the more heavily developed institutional areas associated with the University of New Hampshire. The third subcatchment, identified as 1-Pkg, is a commercial parking lot located in the downtown section of Durham. Runoff from this area is discharged to a small brook which is tributary to the freshwater Oyster River, entering a short distance upstream of the 5-Oys monitoring station. Figure 2 shows the locations of each of these monitoring station. Also shown in Figure 2 are the locations of the eight estuary monitoring stations established to aid in the verification and calibration of the Oyster River Estuary water quality/dispersion model discussed in Section III.

Each of the in-stream monitoring stations and the end-of-pipe station are described in detail below.

FIGURE 2

DURHAM STUDY AREA


NOAA WEATHER STATION
MADBURY RD.
3-Pte.
WATER SUPPLY RESERVOIR
7-Oys.
RTE. 108
2-Pte.
1-Pkg.
RAINGAUGE
SWALE (100' x 10' WITH 2 STATIONS)
1-Coll.
MILL POND
5-Oys.
6-Oys.
TIDAL DAM
47a
47
OYSTER RIVER
48a
DURHAM WWTF
RTE. 108
1-Lng.
48
01
49
49a
50
LEGEND
Flow/Quality Station
Quality Station
1
1/2
0
1 MILE
1000
500
0
1000
2000 METERS

7-Oys (Oyster River at the Water Supply Reservoir)

The Oyster River originates in the southwestern corner of the Town of Barrington, New Hampshire. In its upper reaches it collects drainage from many small streams as it flows southeasterly through Lee and into the water supply reservoir in the western portion of Durham. Below there it flows through town and into the tidal estuary at Route 108.

The 7-Oys subcatchment consists of the upper portion of the drainage basin, that area drained by the 8.5 mile stretch of river above the sampling station on the reservoir dam. The total area of the subcatchment is 10,560 acres. Despite its relatively large size, the catchment population is estimated to number only 300. As is indicated by the low population density, the basin is mostly rural, with 97 percent (10,262 acres) of the land under forest cover. An additional 1.2 percent (136 acres) is comprised of 75 acres of low density residential development, 5 acres of high density residential, 5 acres of institutional land, and a 2-acre section of central business district. In the south-central portion of the subcatchment Wheelwright Pond covers 64 acres.

There are 31 miles of paved road within the 7-Oys basin and 8 miles of dirt road. Route 4, which runs the length of the study area, is the only major highway in the region, with an estimated average daily traffic of 7,000 vehicles per day.

The topography of this subcatchment includes 5 small hills, all approximately 250 feet in elevation. In the lower areas much of the land is marshy. The average slope overall is approximately 2 percent. Half of the soils in the area are of moderately high runoff potential (hydrologic soil group "C"), while another 30 percent are of moderately low runoff potential (hydrologic soil group "B"). Soils in the "A" and "D" hydrologic soil groups only occur in small patches throughout the area.

5-Oys (Oyster River at the Tidehead Dam)

As the Oyster River flows a distance of 8,500 feet from the water supply reservoir to the 5-Oys sampling station on the tidehead dam at Route 108, it collects drainage from 2,181 acres of Durham lands. The portion of this subcatchment north of the River and south of Main Street encompasses most of the buildings and grounds of the University (200 acres), as well as 435 acres of residential land and 10 acres of commercial development immediately adjacent to the campus. Included within this commercial section is the 1-Pkg subcatchment in the Shop n' Save Parking lot, described later in this section.

On the South side of the River, the land is much more rural, consisting of 380 acres of parkland and open space, 270 acres of agricultural land, and 865 acres of forest. Another 21 acres of the 5-Oys subcatchment are water-covered, including the swampy area where Beaudette and Hamel Brooks join the River and, just below there, the shallow Mill Pond, impounded by the tidehead dam.

Most of the population of this subcatchment, estimated at 3,600, is concentrated in the developed area to the north of the River. Consequently, the traffic in that portion of the study area is heavier (approximately 9,500 vehicles per day) than on the back roads crisscrossing the rural sections of the subcatchment (approximately 300 vehicles per day). Those more heavily travelled roads near the center of town are swept with some degree of regularity; weekly on Mill Road, Faculty Road, and Main Street, and at least yearly on the rest. They are also drained, to some extent, by separated storm drains. There are a total of 15.5 miles of asphalt-covered road in the 5-Oys study area.

Nearly 96 percent of the soils within the subcatchment are of the "C" hydrological soil group so common to the entire Durham area. Each of the other three soil groups is represented in this subcatchment; however, the "A" and "B" groups (lower runoff potential) occur on the higher lands and the wetter muck and peat of the "D" group are found along the stream beds. Generally, the subcatchment is fairly flat with an average slope of approximately 4 percent. There are no significant outcroppings within the area.

3-Pte (Upper Pettee Brook)

Pettee Brook is a tributary of the Oyster River which empties into the latter below the wastewater treatment plant in the tidal estuary. Through Durham, the Brook runs parallel to, and north of the Oyster River, collecting drainage from most of the Town north of Main Street. Late summer base flow in the Brook is less than 1 cfs.

The upper part of the Pettee Brook drainage basin, the 3-Pte subcatchment, encompasses 615 acres of predominantly rural land. Over half of the land (320 acres) is forested, with much of the rest open for recreational or parkland purposes or under agricultural use. Only 30 acres of the land are residential (single-family housing), and another 10 acres are in the central business district of the Town. It is estimated that within the entire subcatchment there are 1.3 miles of asphalt road and 1.1 miles of dirt road. Therfore, it can be said that nearly 100 percent of the subcatchment is of pervious cover. With the total population of the subcatchment numbering around 100, it is not expected that traffic is heavy on any of the roads.

Pettee Brook collects its initial drainage off of Beech Hill (elevation 291 feet) in the northernmost portion of the subcatchment. This is the steepest section of the area, with a vertical drop of 180 feet over a half-mile span. The rest of the subcatchment is relatively flat, with an average slope of less than 5 percent. The Brook runs a total length of 15,800 feet upstream of Edgewood Road at the Alumni Center, which is where the 3-Pte sampling station is located. Approximately in the middle of this stretch, the Brook passes through an 11-acre shallow impoundment known as the Old Durham Reservoir.

Soil types in the 3-Pte subcatchment are mostly of the "C" hydrologic soil group. Soils on the north side of the Brook are predominantly the very rocky, or fine sandy loams, while those on the south side are silt loams.

2-Pte (Lower Pettee Brook)

The 2-Pte subcatchment is the area drained by 2,800 feet of Pettee Brook which flows through the more developed part of Durham from the Alumni Center to the sampling station at Madbury Road. Of its 106-acre area, 55 acres are institutional (zoned commercial residential), consisting of fraternity and sorority residences and University offices. In addition, 20 acres are single-family residential, 16 acres are high-density residential, and 15 acres are commercial. Of the commercial land, 9 acres are part of the central business district, and 6 acres are small shopping centers. All of the commercial land is considered to be nearly 100 percent impervious, while the residential portions of the subcatchment are from 20 to 25 percent impervious.

The estimated total population of the 2-Pte subcatchment is approximately 2,600. However, it is important to note that the majority of the populace in the area are comprised of University students, most of whom are not in residence during the summer months. It is estimated that during June, July and August, the population of the area dwindles to around 600.

Likewise, although the traffic through the area may be considered heavy at approximately 6,000 vehicles per day during the academic year, it is significantly less in summer.

There are a total of 2.3 miles of road within this study area, all of which are asphalt-covered, in good condition, and drained by isolated catchbasins which discharge within the subcatchment. According to town officials, the catchbasins are flushed once a year, and the streets are swept at least that often. Pettee Brook lane is swept weekly.

The topography in this area of town is fairly level, with an average slope of approximately 2 percent. All of the soils are witin the "C" hydrologic soil group, with Hollis-Charlton fine, sandy loams covering most of the area. In portions of the stream beds itself, silt loams are more common.

1-Pkg (Shop n' Save Parking Lot)

The Edgewood Shopping Center is part of Durham's commercial area, bordering the University campus. Comprised of the Shop n' Save Supermarket, several fast food restaurants, drugstores, hardware stores, and specialty shops totaling 12 units in all, the shopping center services both the Town and the University populations.

The 1-Pkg study area is one of the busiest sections of the shopping center. It drains an area 33,500 square feet (.77 acre) in size, including the roof of the supermarket and the portion of the parking lot directly in front of it. In addition to shoppers, this section of the lot is used by commuter students unable to park on campus. There are 71 parking spaces in the study area, approximately 80 percent full while the University is in session. During the summer and school vacations, only about 20 percent of the spaces are occupied.

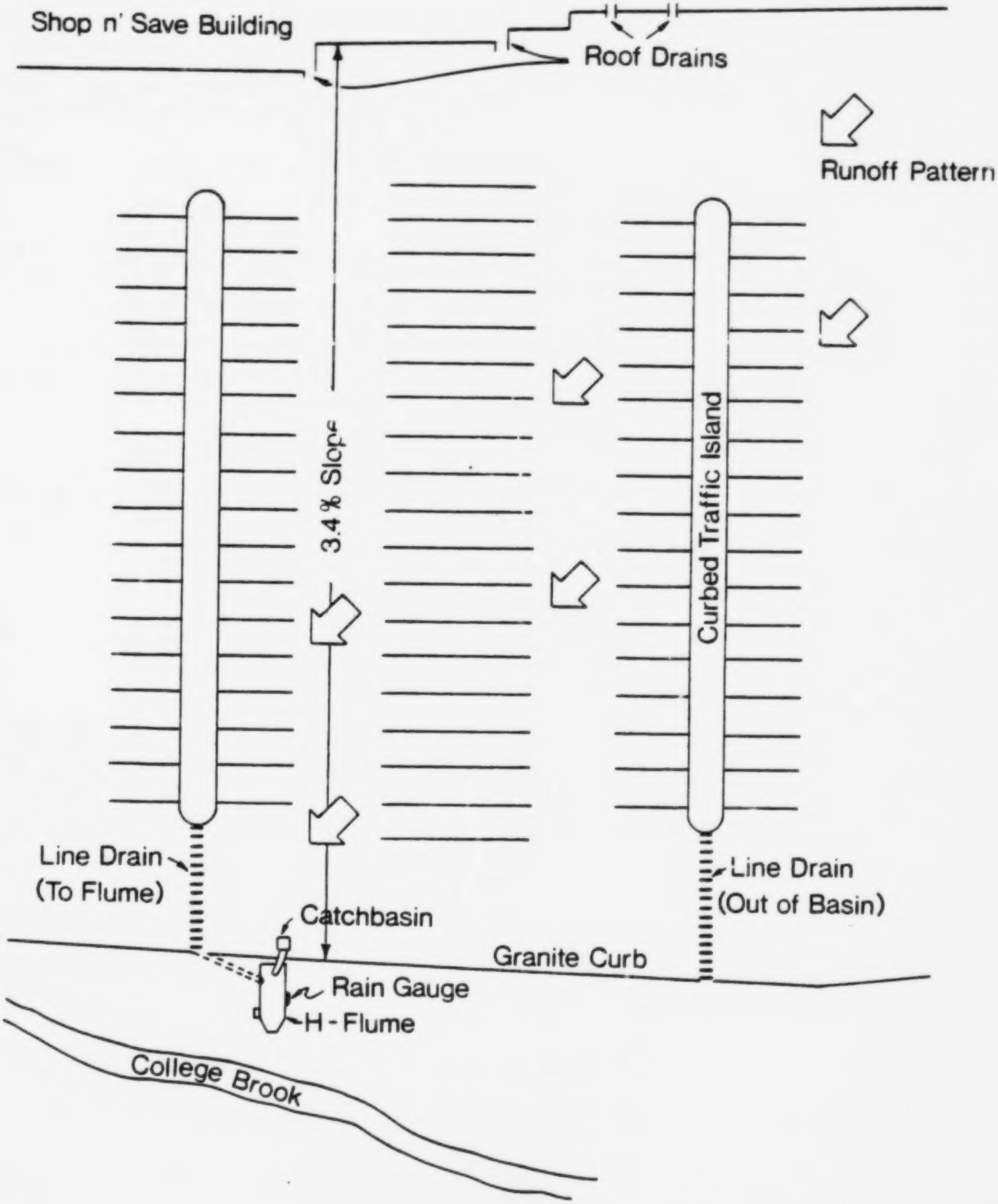
The roof of Shop n' Save, comprising 1 percent of the total drainage area, is flat and gravel-covered. There is a slight degree of pooling and retention of flow in the gravel, but most of the rain falling within the designated roof area drains directly down to the pavement below via 4 open gutters. The parking lot portion of the subcatchment is entirely asphalt covered and slopes away from the stores at approximately 3.2 percent. Extending down to the main traffic aisle on either side of this section of the lot are granite-curbed traffic islands. Drainage is entirely overland flow, channelled by these islands towards the base of the lot, where granite curbing retains the runoff as it drains into a single catchbasin. Since the lot also slopes slightly to the right (looking in the direction of flow), thirty-foot line drains were installed at the end of each traffic island, extending to the base of the lot, to further isolate the flow from the designated study area. The drain on the left (uphill) side collects runoff from outside of the subcatchment and channels it to a separate outflow. The other drain acts in a similar manner, catching runoff from within the study area (which would otherwise escape) and discharging it at a point immediately adjacent to the outflow pipe from the catchbasin. Both of these outflows, from the catchbasin and the on-line drain, discharge flow onto the slope below the base of the lot, where the monitoring station is situated. Eventually, the runoff reaches College Brook, a small stream twenty feet away. Upstream of the site, the stream drains much of the University campus, and downstream it joins the Oyster River above the 5-Oys monitoring site. Figure 3 is a schematic of the 1-Pkg drainage area.

At the beginning of the study period it was discovered that the management of Shop n' Save normally picked up litter and vacuumed the grit in that part of the parking lot every morning. In order to accurately

FIGURE 3

PARKING LOT STUDY CATCHMENT

(.77 ACRE)


Shop n' Save Building
Roof Drains
Runoff Pattern
3.4% Slope
Curbed Traffic Island
Line Drain (To Flume)
Line Drain (Out of Basin)
Catchbasin
Granite Curb
Rain Gauge
H - Flume
College Brook

characterize parking lot runoff before implementation of control measures, it was necessry to request that this practice be temporarily discontinued. The store management was cooperative and agreed to suspend the vacuuming for the year. However, due to concern over customer relations, hand-picking of litter continued throughout the study. Since the sampling equipment used does not pick up large solids (e.g. candy wrappers, paper cups, etc.), the absence of normal litter is not expected to affect the results of the study.

A summary of several important characteristics of each subcatchment is given in Table 1. Land use distributions were obtained by planimeter from maps provided by the Strafford Regional Planning Commission and the Durham Town Offices. Drainage area contributing to the 1-Pkg subcatchment was determined by on-site surveys. Traffic information came from the New Hampshire Department of Public Works and Highways. Soil data were extracted from the Soil Conservation Service's "Soil Survey of Strafford County" and hydrologic data from the United States Geological Survey topographical maps for the area.

Estimates of maximum annual fertilizer application as pounds of nitrogen and pounds of phosphorus were also made for each subcatchment. These estimates were based on average application ranges of the nutrients to different types of agricultural lands. The estimates are maximum annual values for agricultural lands only and do not reflect the fertilizers applied to individual lawns and gardens. It was estimated that private homeowners in Durham use 14 to 19 tons of commercial fertilizer per year, in which there are 8 pounds/ton of nitrogen, 3 pounds/ton of phosphorus, and 6 pounds/ton of potassium.

Table 1

Characterization of Subcatchments

Subcatchment Code	3-Pte	2-Pte	1-Pkg	5-OYS	7-OYS
Area (acres)	615	106	0.918	2,181	10,560
Population density (persons per acre)	0.2	24.5	--	1.6	0.03
Average slope of subcatchment (percent)	5	2	3.2	4	2
Length of main channel (feet)	15,300	2,800	240	8,500	44,880
Average slope of main channel (percent)	1	1	--	1	2
Total street length (lane-miles)	4.8	4.6	--	31.3	78
Impervious cover (percent)	1	27	100	5	1
LAND USE (percent of total area):					
Low Density Residential	5	19	0	20	1
High Density Residential	0	15	0	0	0
Commercial	2	14	100	0	0
Open or Recreational	22	0	0	17	1
Institutional	3	52	0	9	0
Agricultural	14	0	0	12	0
Forest	52	0	0	40	97
Lakes and Wetlands	2	0	0	1	1
HYDROLOGIC SOIL GROUP (percent of total area):					
A	4	0	0	2	14
B	4	0	0	1	30
C	91	100	0	96	50
D	1	0	0	1	6
Estimated fertilizer applications (lb/yr):					
Nitrogen	6,210	5	0	16,338	not avail.
Phosphorus	3,104	2	0	8,152	not avail.

I.3

INSTRUMENTATION

Flow Monitoring

Flow measurement at each of the sites is accomplished with an ISCO Model 1870 flow meter. This instrument is used in conjunction with a primary device, unique to the site, for which a known stage-discharge relationship exists. The meter utilizes a bubbler system, where air supplied by an internal compressor is bubbled out of a small diameter teflon tube and anchored at a designated zero point in the flow stream. Air pressure in the tube corresponds to the liquid level above the tube outlet and is electronically measured. A primary device characterization module is programmed to calculate flow from level, if desired, and either parameter is recorded on an integral strip chart. Cumulative flow is displayed on a totalizer.

Oyster River

The flowmeter at the 7-Oys monitoring station measures and records water level only. The primary device employed is the existing reservoir dam, for which the relationship between level and flow is currently being identified through stream gauging. Gaugings were conducted for a range of flows at a point approximately fifty feet below the dam using a stream velocity meter. A stage-discharge curve with 97 percent correlation has been developed, relating flow to level on a log-log scale. Assuming the dam acts as a weir, flow (Q) is related to head (H) by $Q = aH^b$, or $\log Q = a + b \log H$. The coefficients a and b are dependent on the nature of the weir. The stage-discharge relationship developed for the 7-Oys site is presented in Figure 4.

Due to leakage occurring through the boards at the top of the

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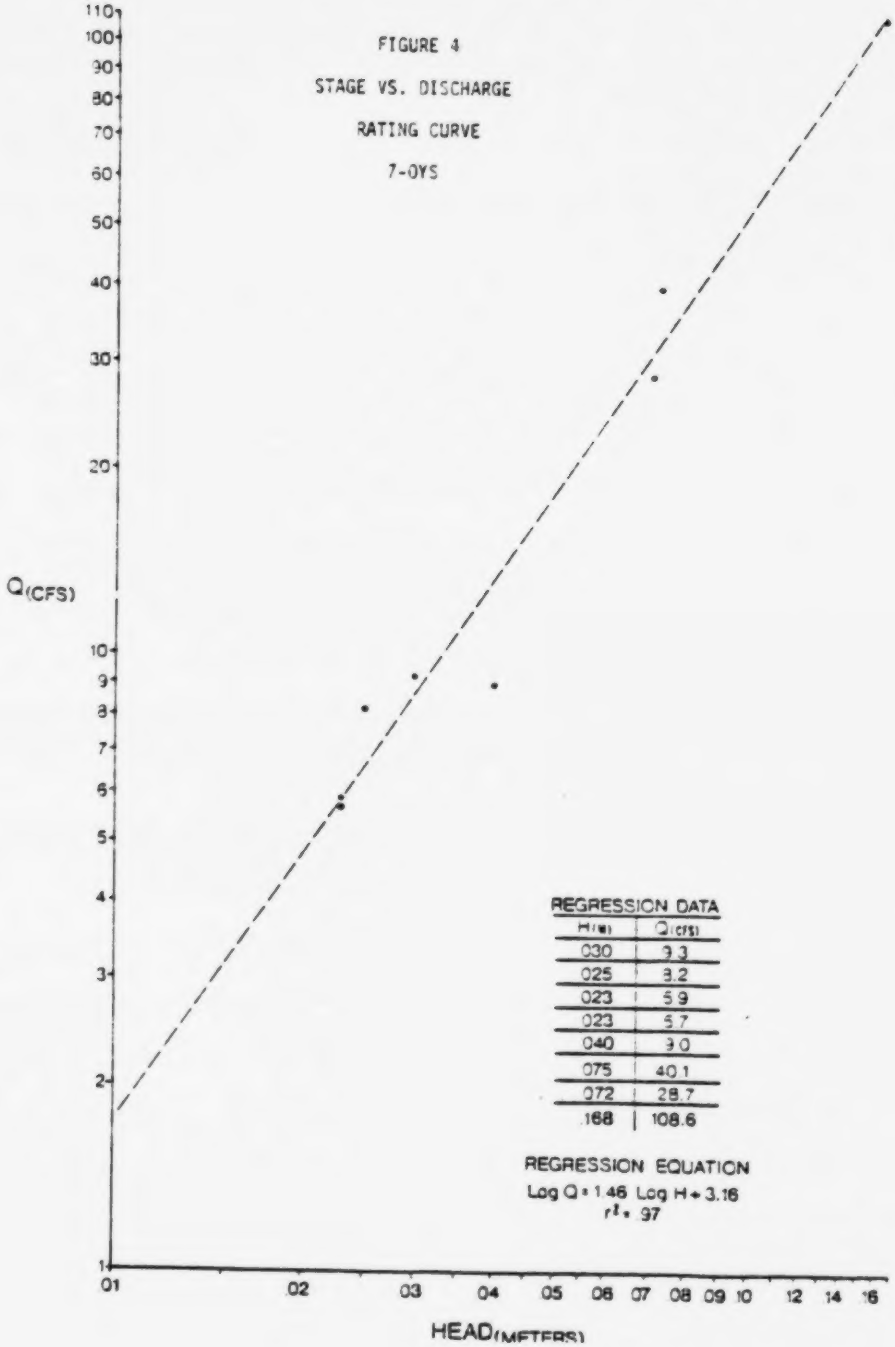
FIGURE 4

STAGE VS. DISCHARGE

RATING CURVE

7-OYS



REGRESSION DATA

H(m)	Q(cfs)
030	9.3
025	8.2
023	5.9
023	5.7
040	9.0
075	40.1
072	28.7
.168	108.6

REGRESSION EQUATION

$\text{Log } Q = 1.46 \text{ Log } H + 3.16$

$r^2 = .97$

dam, a "negative" level may be indicated when the zero level is taken at the top of the boards. Since the flow meter cannot interpret negative levels, the bubble tube at this site was zeroed to a point 0.4 meters below the top of the dam. This built-in factor was subtracted from level readings before conversion to flow. Negative levels with a positive corresponding discharge were not incorporated in the calibration equation. It is estimated that the leakage accounts for less than 3 cfs, which becomes negligible with high storm flows.

The bubble tube at the 7-Oys site is enclosed in a PVC stilling well to minimize level fluctuation caused by wind and waves. It is attached to the wall of the pump hose approximately three feet behind and four feet to one side of the dam.

The 5-Oys site downstream utilizes the tidehead dam, separating the freshwater portion of the River from the tidal estuary, as the primary measuring device. There is a fish ladder on one side of the dam in operation only during the spring and summer. The bubble line to the flow meter is attached to the cement outside wall of the fish ladder six feet upstream of the dam and three feet downstream from the inlet to the fish ladder. It is secured with a PVC stilling well.

As with the 7-Oys site upstream, the flow meter at 5-Oys measures and records liquid pool level only. The River was gauged six times just below the dam to relate level to the corresponding flow over the dam. The calibration curve (Figure 5) developed has a correlation of 90 percent for the range of flows gauged. All stream gaugings were conducted at low tide in order to represent only river flow.

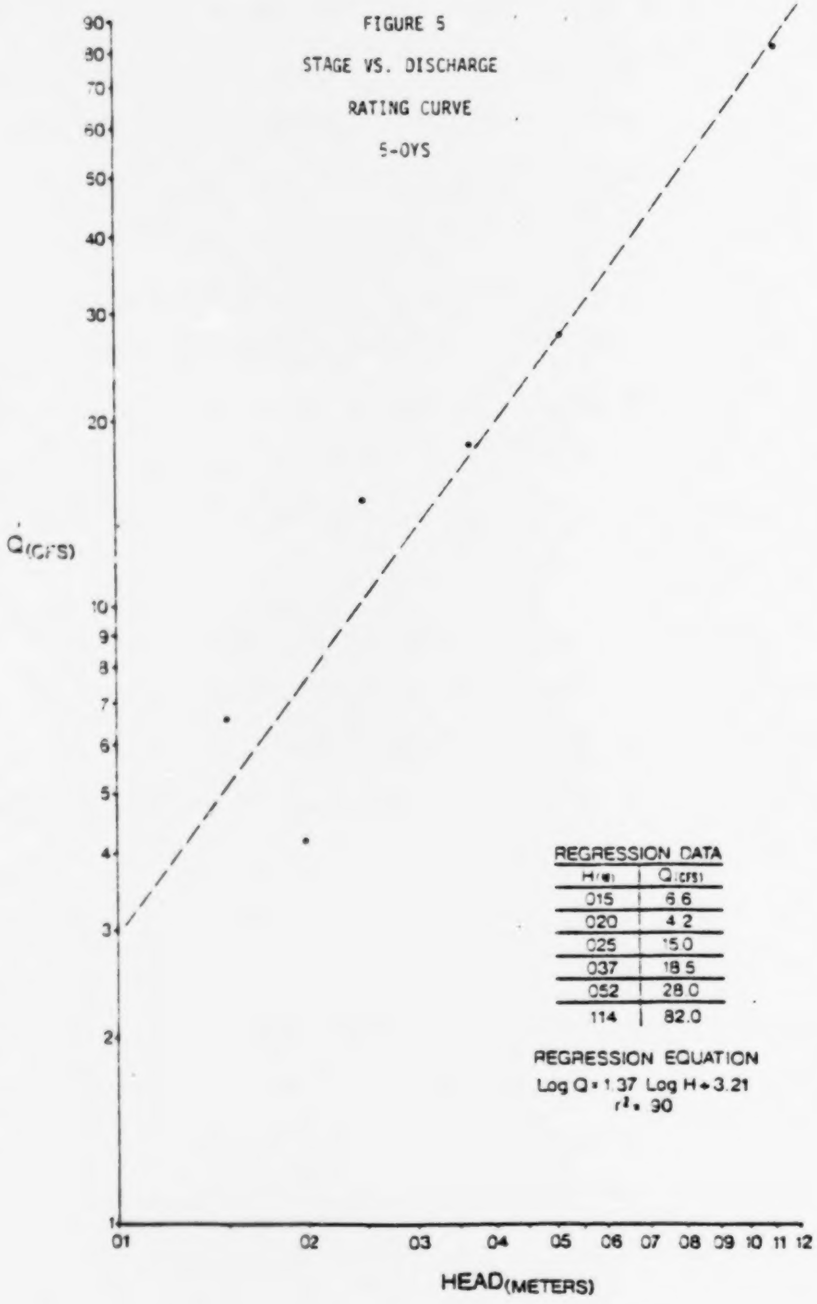


FIGURE 5

STAGE VS. DISCHARGE

RATING CURVE

5-OYS

REGRESSION DATA

H(m)	Q(cfs)
015	6.6
020	4.2
025	15.0
037	18.5
052	28.0
114	82.0

REGRESSION EQUATION

$\text{Log } Q = 1.37 \text{ Log } H + 3.21$

$r^2 = 90$

Pettee Brook

The primary flow measurement device at the 3-Pte sampling station is a two-foot rectangular weir, with end contractions, which spans the upstream end of the culvert crossing under Edgewood Road. The maximum head for the weir is 1.5 feet and the measurable flow range is from 0.74 to 10.4 cubic feet per second (cfs). The bubble tube is enclosed in a larger diameter steel tube to prevent jarring and attached vertically to the rock bank of the stream with the zero elevation at the crest of the weir.

The 2-Pte monitoring station is situated at the downstream end of the rectangular culvert crossing under Madbury Road. The primary device, a six-foot rectangular weir without end contractions, is located inside the culvert approximately six feet from the downstream end. Initially, the primary device characterization module at the site was programmed to convert level to flow up to a maximum head of three feet on the weir, corresponding to a measurable flow range of 1.79 to 104.0 cfs. The module was changed in Novemer to one with a maximum readable head of 1.5 feet, or a maximum flow of 36.71 cfs. The reason for the switch was to expand the recorded hydrograph, accentuating rises in level, by reducing the scale. It had no effect on the accuracy of measurement, as all of the storm flows were well within the reduced range of measurable values. The bubble line for the 2-Pte site, encased in a steel tube, is fastened to the wall approximately four feet upstream of the weir. The level measured is zeroed at the crest of the weir. The approach to the weir through the culvert is long and straight, thus providing superior conditions for flow measurement.

Parking Lot

The 1-Pkg flow measurement device is a two-foot H-flume collecting discharge from two outflow pipes at the base of the parking lot. One of the pipe drains the only catchbasins in the study area, and the other drains the line drain collecting "escaping" flow from the lower side of the basin.

When the wooden flume was installed, it was set into a concrete base and levelled. In addition, the entrance to the flume from the discharge pipe was lined with concrete to prevent leakage. The flume has a rectangular approach eight feet long and discharges flow freely onto the grassy slope below. It is capable of measuring flows from 0.024 to 11.0 cfs. For level measurement, the flow meter bubble tube is attached within a stilling well on one side of the flume.

Water Quality Monitoring

Phase I water quality sampling was conducted in Durham from May 1980 through November 1982. In all, forty-three storm events were monitored, although not at each station. In addition, a total of twenty-seven dates were sampled at each fresh water river station for the purpose of characterizing base flow water quality. Estuary sampling was conducted a total of eleven times each at eight stations. Sixteen storm events were sampled for rainfall water quality.

Stormwater runoff quality samples were collected with ISCO Model 1680 samplers. These units are capable of collecting up to twenty-eight separate one-half liter samples. Programming of the unit enables discrete or composite sampling on time or flow bases. Sample volumes and intervals were adjusted several times throughout the course of this study according to changes in base flow and the volumes of runoff anticipated.

With the ISCO sampler, samples are collected through a screen-tipped plastic suction line anchored in the flow stream. The peristaltic pump mechanism purges the suction line automatically before and after each sample is drawn to prevent cross-contamination.

Base flow quality characterization and estuarine samples were collected manually. Precipitation quality samples were collected with a plastic thirty-gallon container lined with a plastic bag. Efforts were made to keep the collector covered in dry periods to reduce the effects of dry fallout on rainfall quality determinations.

Oyster River

Samplers at the two Oyster River locations were operated on a time-constant basis with the sampling routine initiated by an ISCO Model 1640 liquid level actuator. The actuator has a moisture-sensitive probe tip which, when wetted by a rise in the liquid level, sends a signal to the sampler to begin collection. Once initiated, samples are collected at set intervals until liquid level recedes. Prior to each anticipated storm event, the actuators at 5-Oys and 7-Oys were adjusted to initiate sampling with a rise in pool level of approximately one-eighth inch. The actuators were located in stilling wells (four-inch PVC) at both sites.

Sampler intake lines at 5-Oys and 7-Oys were attached to the walls of the fish ladder and the pump house, respectively. Pump flow rate in the sampler was sufficient to prevent sedimentation of heavy particles in the line.

Stormwater runoff samples collected at the 5-Oys and 7-Oys monitoring stations were composited for each storm sampled. Since the samples were collected on a time-constant basis, they were manually proportioned based on their time of occurrence on the hydrograph.

Pettee Brook

At the 2-Pte and 3-Pte sites the samplers were operated on a flow-proportioned basis in conjunction with the flow meter. In this operational mode, the sampler receives electronic pulses from the flow meter at designated intervals of flow and is programmed to count a preset number of pulses between samples. When operated in flow mode, the flow meter records an "event mark" on the flow hydrograph as each sample is drawn. The marks allow for later determination of instantaneous flow rate associated with each sample, as well as the time of sample collection.

The sampler intake at the 2-Pte station was fastened in a vertical position to the wall of the culvert several feet upstream of the weir. The intake at the upstream 3-Pte station was anchored to the floor of the culvert just below the weir. Flow in this portion of the stream is turbulent due to the flow over the weir, so no settling of solids occurred. Samples were collected from a point about mid-depth in the flow stream.

Parking Lot

Sampling at the 1-Pkg site was conducted on a flow-proportioned basis in conjunction with a flow meter. Since sampling occurred only during runoff events, it was possible to program the sampler to collect the initial runoff flow at the station. This arrangement was not possible at the stream sampling stations due to continuous base flow.

The sampler intake at the site is anchored to the floor at the head of the H-flume in order to collect representative samples before settling occurs with the steadying of flow through the device.

I.4 WATER QUALITY DATA COLLECTION AND SUMMARY

In addition to flow measurements at each site, stormwater and base flow quality were analyzed for many potential contaminants. Stormwater runoff sampling included both flow weighted composite water quality samples and discrete (grab) samples collected during the runoff event. Stormwater grab samples were also collected at the parking lot site for Priority Pollutant analyses.

Rainfall volume data was obtained from the National Weather Service station in Durham. The station is located in the field adjacent to the forestry building, within the 5-Oys subcatchment, and no farther than two miles from any of the stream sampling stations. Since summertime thunderstorm activity frequently exhibited spatial differences in precipitation volumes produced within the study area, a plastic rain gauge was installed at the parking lot site. Data collected at this gauge were used when necessary.

Where possible, water quality sample collection procedures were performed according to Environmental Protection Agency (1978) or Standard Methods (1980) protocols. Stormwater composite sampling for bacteriological parameters precluded adherence to the recommended grab sampling technique and, in some instances, the 6-hour holding period. These data, although questionable in terms of absolute concentrations, are still quite useful for trend comparisons between stations and for comparison with base flow quality within stations.

Laboratory analysis procedures follow protocols presented in the report Quality Assurance and Control Program (New Hampshire Water Supply and Pollution Control Commission, 1981).

Summary statistics of specific contaminant concentrations for each of these separate efforts are presented in Tables 2 through 16.

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DRY WEATHER DATA

TABLE 2

3-PTE/UPPETTEBK 3-PTE
43 08 22.0 070 55 57.0 4
UPSTREAM/PETTEE BK/BACKGROUND/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590868-2954311

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
WATER	TEMP	CENT	17	14.6176	20.7978	4.56046	.311984	1.10607	22.0000	5.00000
CONDUCTVY	AT 25C	MICROMHO	17	255.282	8993.37	94.8334	.371485	23.0005	491.000	159.000
BOD	5 DAY	MG/L	17	1.75882	.201333	.448701	.255115	.108826	2.70000	.900000
COD	HI LEVEL	MG/L	17	30.2646	248.246	15.7558	.520602	3.82135	63.7000	4.30000
LAB	PH	SU	17	7.16470	.0686950	.262097	.0365818	.0635679	7.80000	6.50000
T ALK	CACO3	MG/L	16	42.5874	112.727	10.6173	.249305	2.65432	60.0000	20.8000
RESIDUE	TOTAL	MG/L	16	181.437	5165.46	71.8711	.396121	17.9678	370.000	100.000
RESIDUE	TOT VOL	MG/L	1	201.000					201.000	201.000
RESIDUE	TOT NFLT	MG/L	14	7.28571	22.5275	4.74631	.651455	1.26850	21.0000	2.00000
NH3+NH4-	N TOTAL	MG/L	17	.150588	.0414058	.203484	1.35126	.0493521	.940000	.100000
TOT KJEL	N	MG/L	10	.775999	.122271	.349673	.450610	.110576	1.20000	.0000000
NO2&NO3	N-TOTAL	MG/L	17	.297058	.0296969	.172328	.580115	.0417957	.620000	.0600000
ORTHOPO4	PO4	MG/L	17	.0057059	.0000411	.0064106	1.12351	.0015548	.0180000	.0010000
PHOS-TOT		MG/L P	12	.0729999	.0067834	.0823615	1.12824	.0237757	.330000	.0310000
MGNSIUM	MG,DISS	MG/L	1	3.00000					3.00000	3.00000
MGNSIUM	MG,TOT	MG/L	12	3.14583	.346133	.588331	.187019	.169836	4.10000	1.75000
SODIUM	NA,TOT	MG/L	3	20.3333	30.3337	5.50761	.270866	3.17982	26.0000	15.0000
PTSSIUM	K,DISS	MG/L	1	2.80000					2.80000	2.80000
PTSSIUM	K,TOT	MG/L	2	3.10000	.0000000	.0000000	.0000000	.0000000	3.10000	3.10000
CHLORIDE	TOTAL	MG/L	16	40.3125	438.762	20.9467	.519607	5.23666	92.0000	27.0000
CADMIUM	CD,DISS	UG/L	1	5.00000					5.00000	5.00000
CADMIUM	CD,TOT	UG/L	15	4.99999	.0000349	.0059057	.0011811	.0015248	5.00000	5.00000
CHROMIUM	CR,DISS	UG/L	1	10.00000					10.00000	10.00000
CHROMIUM	CR,TOT	UG/L	15	12.6667	49.5239	7.03732	.555579	1.81703	30.0000	10.00000
COPPER	CU,DISS	UG/L	1	100.0000					100.0000	100.0000
COPPER	CU,TOT	UG/L	15	93.9998	540.004	23.2380	.247213	6.00002	100.0000	10.00000
IRON	FE,TOT	UG/L	15	893.331	96385.1	310.459	.347530	80.1603	1800.00	500.000
IRON	FE,DISS	UG/L	1	600.000					600.000	600.000
LEAD	PB,DISS	UG/L	1	10.00000					10.00000	10.00000
LEAD	PB,TOT	UG/L	15	10.3333	1.66678	1.29104	.124939	.333345	15.0000	10.00000
MANGNESE	MN	UG/L	15	216.666	13866.7	117.757	.543494	30.4047	560.000	90.0000
MANGNESE	MN,DISS	UG/L	1	220.000					220.000	220.000
NICKEL	NI,TOTAL	UG/L	11	.0999999	.1783E-07	.0001337	.0013372	.0000403	.100000	.100000
ZINC	ZN,DISS	UG/L	1	10.00000					10.00000	10.00000
ZINC	ZN,TOT	UG/L	14	16.4285	86.2641	9.28785	.565348	2.48228	40.0000	10.00000
TOT COLI	MPN CONF	TUBECODE	17	296.353	5570.75	74.6374	.251853	18.1022	400.000	100.000
FEC COLI	MPN	TUBECODE	17	172.588	5075.64	71.2435	.412795	17.2791	300.000	70.0000
FEC STRP	MPN-KFBR	TUBE CD	17	206.059	4618.19	67.9572	.329795	16.4820	281.000	70.0000
STREAM.	FLOW.	INST-CFS	15	.967999	.140373	.374663	.387049	.0967376	1.13000	.0500000

DRY WEATHER DATA

TABLE 3

2-PTE/DNPETTEBK 2-PTE
43 08 06.0 070 55 33.0 4
DNSTREAM/PETTEE BK/SOURCE MONITOR/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590867-2954310

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
WATER	TEMP	CENT	16	13.2937	18.9073	4.34825	.327090	1.08706	21.0000	3.00000
CONDUCTVY	AT 25C	MICROMHO	15	430.467	507082	712.097	1.65424	183.863	2997.00	178.000
BOD	5 DAY	MG/L	16	1.58750	.398499	.631267	.397649	.157817	3.20000	.400000
COD	HI LEVEL	MG/L	16	33.2000	195.433	13.9797	.421076	3.49493	59.8000	7.50000
LAB	PH	SU	16	7.34999	.0399902	.199976	.0272076	.0499939	7.80000	7.00000
T ALK	CACO3	MG/L	15	42.8399	90.9668	9.53765	.222634	2.46261	59.5000	22.0000
RESIDUE	TOTAL	MG/L	13	153.462	1085.28	32.9435	.214670	9.13689	247.000	115.000
RESIDUE	TOT NFLT	MG/L	14	6.50007	19.0375	4.36320	.671253	1.16611	18.0000	.0010000
RESIDUE	VOL NFLT	MG/L	1	4.00000					4.00000	4.00000
NH3+NH4-	N TOTAL	MG/L	16	.101250	.0000250	.0050042	.0494242	.0012510	.120000	.100000
TOT KJEL	N	MG/L	10	.706000	.0279824	.167279	.236940	.0528984	.990000	.500000
NO2&NO3	N-TOTAL	MG/L	16	.250000	.0117201	.108259	.433038	.0270648	.400000	.0500000
ORTHOPO4	PO4	MG/L	16	.0032500	.0000106	.0032557	1.00177	.0008139	.0130000	.0010000
PHOS-TOT		MG/L P	10	.0351000	.0002861	.0169145	.481895	.0053488	.0659999	.0010000
MGNSIUM	MG,DISS	MG/L	1	3.00000					3.00000	3.00000
MGNSIUM	MG,TOT	MG/L	8	3.54375	.196753	.443569	.125169	.156825	4.20000	2.80000
SODIUM	NA,TOT	MG/L	4	18.2500	74.9167	8.65544	.474271	4.32772	26.0000	7.00000
PTSSIUM	K,DISS	MG/L	1	2.90000					2.90000	2.90000
PTSSIUM	K,TOT	MG/L	2	3.25000	.0449982	.212128	.0652700	.149997	3.40000	3.10000
CHLORIDE	TOTAL	MG/L	14	38.2500	238.029	15.4282	.403351	4.12335	89.0000	29.0000
CADMIUM	CD,DISS	UG/L	1	5.00000					5.00000	5.00000
CADMIUM	CD,TOT	UG/L	11	4.99999	.0000977	.0098821	.0019764	.0029796	5.00000	5.00000
CHROMIUM	CR,DISS	UG/L	1	10.00000					10.00000	10.00000
CHROMIUM	CR,TOT	UG/L	11	17.2727	181.818	13.4840	.780653	4.06557	50.0000	10.00000
COPPER	CU,DISS	UG/L	1	100.0000					100.0000	100.0000
COPPER	CU,TOT	UG/L	11	99.9998	.0187500	.136931	.0013693	.0412861	100.0000	100.0000
IRON	FE,TOT	UG/L	11	799.999	50002.1	223.611	.279515	67.4214	1200.00	400.000
IRON	FE,DISS	UG/L	1	400.000					400.000	400.000
LEAD	PB,DISS	UG/L	1	10.00000					10.00000	10.00000
LEAD	PB,TOT	UG/L	11	10.4545	2.27288	1.50761	.144206	.454560	15.0000	10.00000
MANGNESE	MN	UG/L	11	121.818	1136.39	33.7103	.276727	10.1641	180.000	70.0000
MANGNESE	MN,DISS	UG/L	1	150.000					150.000	150.000
NICKEL	NI,TOTAL	UG/L	7	.100000	.0000000	.0000000	.0000000	.0000000	.100000	.100000
ZINC	ZN,DISS	UG/L	1	10.00000					10.00000	10.00000
ZINC	ZN,TOT	UG/L	10	18.0000	151.111	12.2927	.682929	3.88730	50.0000	10.00000
TOT COLI	MPN CONF	TUBECODE	16	330.812	2185.93	46.7540	.141331	11.6885	400.000	248.000
FEC COLI	MPN	TUBECODE	16	213.625	2412.78	49.1201	.229936	12.2800	300.000	100.000
FEC STRP	MPN-KFBR	TUBE CD	16	250.250	1091.13	33.0323	.131997	8.25808	300.000	201.000
STREAM	FLOW,	INST-CFS	16	.985562	.131562	.362715	.368028	.0906786	1.14000	.0490000

DRY WEATHER DATA

TABLE 4

7-OYS/UPOYSTER 7-OYS
43 07 57.0 070 56 27.0 4
UPSTREAM/OYSTER R/BACKGROUND/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590873-2954316

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
WATER	TEMP	CENT	18	15.0833	44.7135	6.68681	.443325	1.57610	27.0000	3.00000
CONDUCTVY	AT 25C	MICROMHO	18	176.767	2397.38	48.9630	.276992	11.5407	263.000	98.0000
BOD	5 DAY	MG/L	18	1.67777	.315960	.562103	.335029	.132489	3.20000	.900000
COD	HI LEVEL	MG/L	17	30.3235	87.4028	9.34895	.308307	2.26745	51.7000	15.8000
LAB	PH	SU	18	7.14444	.155532	.394375	.0552003	.0929551	7.90000	6.50000
T ALK	CACO3	MG/L	17	24.8882	55.9123	7.47746	.300442	1.81355	38.6000	11.6000
RESIDUE	TOTAL	MG/L	16	127.312	841.429	29.0074	.227844	7.25185	175.000	76.0000
RESIDUE	TOT VOL	MG/L	1	83.0000					83.0000	83.0000
RESIDUE	TOT NFLT	MG/L	16	7.68756	90.0948	9.49183	1.23470	2.37296	39.0000	.0010000
RESIDUE	VOL NFLT	MG/L	2	1.50000	.500000	.707107	.471404	.500000	2.00000	1.00000
NH3+NH4-	N TOTAL	MG/L	18	.0999997	.5259E-07	.0002293	.0022933	.0000541	.100000	.100000
TOT KJEL	N	MG/L	15	.543333	.0133954	.115738	.213016	.0298835	.800000	.380000
NO2&NO3	N-TOTAL	MG/L	17	.274117	.0133009	.115329	.420731	.0279715	.430000	.0500000
ORTHOPO4	PO4	MG/L	18	.0024444	.0000051	.0022550	.922495	.0005315	.0100000	.0010000
PHOS-TOT		MG/L P	12	.0336666	.0002439	.0156167	.463861	.0045081	.0799999	.0170000
MGNSIUM	MG,DISS	MG/L	2	2.15000	.245001	.494976	.230221	.350001	2.50000	1.80000
MGNSIUM	MG,TOT	MG/L	13	2.79846	.777302	.881647	.315048	.244525	4.10000	1.47000
SODIUM	NA,TOT	MG/L	6	12.6667	8.66675	2.94393	.232416	1.20186	15.0000	9.00000
SODIUM	NA,DISS	MG/L	1	14.0000					14.0000	14.0000
PTSSIUM	K,DISS	MG/L	2	1.05000	.125001	.353555	.336719	.250001	1.30000	.800000
PTSSIUM	K,TOT	MG/L	2	1.75000	.125000	.353553	.202030	.250000	2.00000	1.50000
CHLORIDE	TOTAL	MG/L	18	31.1111	85.2819	9.23482	.296834	2.17667	47.0000	15.0000
CADMIUM	CD,DISS	UG/L	2	5.00000	.0000000	.0000000	.0000000	.0000000	5.00000	5.00000
CADMIUM	CD,TOT	UG/L	15	5.13332	.266689	.516419	.100601	.133339	7.00000	5.00000
CHROMIUM	CR,DISS	UG/L	2	20.0000	200.000	14.1421	.707107	10.0000	30.0000	10.00000
CHROMIUM	CR,TOT	UG/L	15	12.6667	49.5239	7.03732	.555579	1.81703	30.0000	10.00000
COPPER	CU,DISS	UG/L	2	100.0000	.0000000	.0000000	.0000000	.0000000	100.0000	100.0000
COPPER	CU,TOT	UG/L	15	99.9998	.0089286	.0944911	.0009449	.0243975	100.0000	100.0000
IRON	FE,TOT	UG/L	15	793.331	72098.7	268.512	.338462	69.3296	1300.00	300.000
IRON	FE,DISS	UG/L	2	400.000	.0000000	.0000000	.0000000	.0000000	400.000	400.000
LEAD	PB,DISS	UG/L	2	9.99999	.0001831	.0135316	.0013532	.0095683	10.00000	10.00000
LEAD	PB,TOT	UG/L	15	10.6667	6.66676	2.58201	.242064	.666672	20.0000	10.00000
MANGNESE	MN	UG/L	15	80.6664	620.969	24.9192	.308917	6.43412	120.000	40.0000
MANGNESE	MN,DISS	UG/L	2	45.0000	449.999	21.2132	.471404	15.0000	60.0000	30.0000
NICKEL	NI,TOTAL	UG/L	11	.0999999	.1788E-07	.0001337	.0013372	.0000403	.100000	.100000
ZINC	ZN,DISS	UG/L	2	40.0000	1799.99	42.4263	1.06066	30.0000	70.0000	10.00000
ZINC	ZN,TOT	UG/L	14	18.5714	567.033	23.8125	1.28221	6.36415	100.0000	10.00000
TOT COLI	MPN CONF	TUBECODE	17	258.823	3891.62	62.3829	.241025	15.1301	373.000	148.000
FEC COLI	MPN	TUBECODE	15	138.000	2487.14	49.8713	.361386	12.8767	206.000	70.0000
FEC STRP	MPN-KFBR	TUBE CD	17	182.294	5121.10	71.5619	.392563	17.3563	300.000	70.0000
STREAM	FLOW,	INST-CFS	17	10.4059	293.876	17.1428	1.64742	4.15774	71.7000	3.00000

DRY WEATHER DATA

TABLE 5

5-OYS/DNOYSTER 5-OYS
43 07 50.0 070 55 11.0 4
DNSTREAM/OYSTER R/SOURCE MONITOR/DURHAM NH
33017   NEW HAMPSHIRE   STRAFFORD
NORTH ATLANTIC   021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590872-2954315

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
WATER	TEMP	CENT	16	15.9875	36.4822	6.04005	.377799	1.51001	26.0000	4.00000
CONDUCTVY	AT 25C	MICROMHO	16	191.831	2712.57	52.0823	.271501	13.0206	275.000	109.000
BOD	5 DAY	MG/L	16	2.30000	1.29201	1.13667	.494203	.284166	4.90000	1.10000
COD	HI LEVEL	MG/L	14	30.0500	101.719	10.0856	.335627	2.69549	47.0000	7.90000
LAB	PH	SU	16	7.16249	.0864745	.294066	.0410563	.0735163	7.90000	6.70000
T ALK	CACO3	MG/L	15	29.6399	60.8365	7.79977	.263151	2.01389	43.2000	14.3000
RESIDUE	TOTAL	MG/L	13	130.077	860.583	29.3357	.225526	8.13626	173.000	86.0000
RESIDUE	TOT VOL	MG/L	1	87.0000					87.0000	87.0000
RESIDUE	TOT NFLT	MG/L	13	4.23077	11.1923	3.34549	.790752	.927872	10.0000	1.00000
RESIDUE	VOL NFLT	MG/L	2	1.50000	.500000	.707107	.471404	.500000	2.00000	1.00000
NH3+NH4-	N TOTAL	MG/L	16	.103750	.0002250	.0150014	.144593	.0037504	.160000	.100000
TOT KJEL	N	MG/L	11	.506363	.0452857	.212804	.420260	.0641629	.710000	.100000
NO2&NO3	N-TOTAL	MG/L	16	.193750	.0670648	.258969	1.33662	.0647422	1.13000	.0500000
ORTHOPO4	PO4	MG/L	16	.0033750	.0000066	.0025788	.764076	.0006447	.0090000	.0010000
PHOS-TOT		MG/L P	12	.0325833	.0001577	.0125587	.385433	.0036254	.0540000	.0100000
MGNSIUM	MG,DISS	MG/L	2	2.35000	.244999	.494974	.210627	.349999	2.70000	2.00000
MGNSIUM	MG,TOT	MG/L	10	2.68500	.451148	.671676	.250159	.212402	4.00000	1.80000
SODIUM	NA,TOT	MG/L	5	13.4000	26.8001	5.17688	.386335	2.31517	18.0000	6.00000
SODIUM	NA,DISS	MG/L	1	16.0000					16.0000	16.0000
PTSSIUM	K,DISS	MG/L	2	1.60000	.179999	.424263	.265165	.300000	1.90000	1.30000
PTSSIUM	K,TOT	MG/L	3	2.00000	.490001	.700001	.350001	.404146	2.70000	1.30000
CHLORIDE	TOTAL	MG/L	16	31.4375	89.0625	9.43729	.300192	2.35932	53.0000	16.0000
CADMIUM	CD,DISS	UG/L	1	5.00000					5.00000	5.00000
CADMIUM	CD,TOT	UG/L	12	5.41665	2.08336	1.44339	.266472	.416670	10.00000	5.00000
CHROMIUM	CR,DISS	UG/L	2	20.0000	200.000	14.1421	.707107	10.0000	30.0000	10.00000
CHROMIUM	CR,TOT	UG/L	12	13.3333	60.6062	7.78499	.583875	2.24733	30.0000	10.00000
COPPER	CU,DISS	UG/L	2	100.0000	.0000000	.0000000	.0000000	.0000000	100.0000	100.0000
COPPER	CU,TOT	UG/L	12	99.9998	.0170455	.130558	.0013056	.0376889	100.0000	100.0000
IRON	FE,TOT	UG/L	12	841.665	117200	342.345	.406748	98.8266	1500.00	500.000
IRON	FE,DISS	UG/L	2	500.000	.0000000	.0000000	.0000000	.0000000	500.000	500.000
LEAD	PB,DISS	UG/L	1	10.00000					10.00000	10.00000
LEAD	PB,TOT	UG/L	12	9.99999	.0001110	.0105344	.0010534	.0030410	10.00000	10.00000
MANGNESE	MN	UG/L	12	101.666	6978.77	83.5390	.821697	24.1156	320.000	30.0000
MANGNESE	MN,DISS	UG/L	2	75.0000	50.0000	7.07107	.0942808	5.00000	80.0000	70.0000
NICKEL	NI,TOTAL	UG/L	8	.100000	.0000000	.0000000	.0000000	.0000000	.100000	.100000
ZINC	ZN,DISS	UG/L	2	45.0000	2450.00	49.4974	1.09994	35.0000	80.0000	10.00000
ZINC	ZN,TOT	UG/L	11	25.4545	547.273	23.3939	.919046	7.05352	80.0000	10.00000
TOT COLI	MPN CONF	TUBECODE	16	266.062	3469.53	58.9027	.221387	14.7257	352.000	170.000
FEC COLI	MPN	TUBECODE	16	146.750	2581.40	50.8075	.346218	12.7019	237.000	70.0000
FEC STRP	MPN-KFBR	TUBE CD	16	190.125	5088.51	71.3338	.375194	17.8334	313.000	70.0000
STREAM	FLOW,	INST-CFS	15	15.9267	539.981	23.2375	1.45903	5.99990	92.0000	3.00000

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                                                       TABLE 6    3-PTE/UPPETTEBK 3-PTE
STORMWATER RUNOFF COMPOSITE SAMPLING DATA                         43 08 22.0 070 55 57.0  4
                                                                  UPSTREAM/PETTEE BK/BACKGROUND/DURHAM NH
                                                                  33017 NEW HAMPSHIRE       STRAFFORD
                                                                  NORTH ATLANTIC            021000
                                                                  PISCATAGUA RIVER AND NEW HAMPSHIRE COAST
                                                                  22NHCITY  810509
                                                                   0000  CLASS 04 CSN-RSP 0590868-2954311

PARAMETER
                               RMK  NUMBER      MEAN  VARIANLE  STAN DEV  COEF VAR  STAND ER   MAXIMUM   MINIMUM BEG DATE END DATE
TURB       TRBIDMTR  HACH FTU            10   52.3900   1532.44   39.1464   .744369   12.3792   130.000   14.9000 81/04/30 81/11/06
CNDUCTVY   AT 25C    MICROMHO            16   206.687   3826.50   61.8587   .299286   15.4647   347.000   85.0000 80/09/18 81/11/06
                               L          1   225.000                                           225.000   225.000 80/11/25 80/11/25
                               TOT       17   207.765   3607.07   60.0589   .289072   14.5664   347.000   85.0000 80/09/18 81/11/06
PRECIP     DURATION  MINUTES             19   552.895    151285   388.953   .703485   89.2319   1680.00   60.0000 80/09/18 81/11/06
DRY DAYS   PRECEDNG  PRECIP              19   5.73684   13.2047   3.63383   .633419   .833657   15.0000   1.00000 80/09/18 81/11/06
BOD        5 DAY     MG/L                15   10.1467   45.9441   6.77821   .668023   1.75012   26.6000   1.80000 80/09/18 81/10/02
COD        HI LEVEL  MG/L                18   40.1555   303.780   17.4293   .361937   4.10812   79.6000   16.0000 80/09/18 81/11/06
LAB        PH        SU                  17   7.02353   .059387   .243695   .034697   .059105   7.50000   6.50000 80/09/18 81/10/27
T ALK      CACO3     MG/L                11   37.0545   76.2984   8.73490   .225731   2.63367   52.6000   21.0000 81/05/29 81/10/27
RESIDUE    TOTAL     MG/L                18   248.944   12986.0   113.956   .457757   26.8597   614.000   120.000 80/09/18 81/11/06
RESIDUE    TOT VOL   MG/L                11   78.3636   680.662   26.0895   .332929   7.86628   112.000   32.0000 81/04/30 81/11/06
RESIDUE    TOT NFLT  MG/L                16   110.187   10709.2   103.485   .939175   25.8713   412.000   24.0000 80/09/18 81/11/06
                               K          1   1.00000                                           1.00000   1.00000 81/07/29 81/07/29
                               TOT       17   103.765   10741.2   103.640   .998796   25.1363   412.000   1.00000 80/09/18 81/11/06
RESIDUE    VOL NFLT  MG/L                11   16.2727   194.618   13.9506   .857298   4.20625   54.0000   7.00000 81/04/30 81/11/06
                               K          1   1.00000                                           1.00000   1.00000 81/07/29 81/07/29
                               TOT       12   15.0000   196.364   14.0130   .934199   4.04520   54.0000   1.00000 81/04/30 81/11/06
NH3+NH4-   N TOTAL   MG/L                 6   .205000   .038030   .195013   .951284   .079614   .600000   .100000 81/04/30 81/11/06
                               K         10   .100000   .000000   .000000             .000000   .100000   .100000 80/09/18 81/10/27
                               TOT       16   .139375   .015433   .124229   .891333   .031057   .600000   .100000 80/09/18 81/11/06
TOT KJEL   N         MG/L                14   2.11142   8.33656   2.88731   1.36747   .771666   12.0000   .880000 80/10/26 81/11/06
NO2&NO3    N-TOTAL   MG/L                18   .538888   .038799   .196974   .365520   .046427   .890000   .290000 80/09/18 81/11/06
ORTHOPO4   PO4       MG/L                17   .010647   .000061   .007794   .732016   .001890   .026000   .002000 80/09/18 81/11/06
                               K          2   .000500  .499E-06   .000707   1.41421   .000500   .001000   .000000 81/09/16 81/09/19
                               TOT       19   .009579   .000064   .008016   .836847   .001839   .026000   .000000 80/09/18 81/11/06
PHOS-TOT             MG/L P              15   .187266   .014425   .120106   .641364   .031011   .462000   .058000 80/10/03 81/11/06
                               L          2   .395000   .000050   .007072   .017903   .005000   .400000   .390000 80/09/18 80/09/26
                               TOT       17   .211706   .017385   .131852   .622808   .031979   .462000   .058000 80/09/18 81/11/06
MGNSIUM    MG.DISS   MG/L                 3   2.26667   .373328   .611006   .269562   .352764   2.80000   1.60000 81/04/30 81/07/29
MGNSIUM    MG.TOT    MG/L                20   3.87799   3.06308   1.75016   .451307   .391349   7.95000   .910000 80/09/18 81/11/06
SODIUM     NA.TOT    MG/L                19   19.9158   125.530   11.2040   .562569   2.57037   52.0000   8.00000 80/09/18 81/11/06
SODIUM     NA.DISS   MG/L                 2   15.1000   7.22021   2.68705   .177950   1.90003   17.0000   13.2000 81/05/29 81/07/29
PTSSIUM    K.DISS    MG/L                 2   3.45000   .844986   .919231   .266444   .649995   4.10000   2.30000 81/05/29 81/07/29
PTSSIUM    K.TOT     MG/L                12   3.85000   .775482   .880615   .228731   .254211   5.00000   2.00000 81/05/29 81/10/27
CHLORIDE   TOTAL     MG/L                18   30.3055   240.858   15.5196   .512104   3.65800   74.0000   12.0000 80/09/18 81/11/06
CADMIUM    CD.DISS   UG/L      K          3   5.00000   .000000   .000000             .000000   5.00000   5.00000 81/04/30 81/07/29
CADMIUM    CD.TOT    UG/L                 2   8.00000   7.99998   2.82842   .353553   2.00000  10.00000   6.00000 80/10/26 81/11/06
                               K         16   11.5625   559.059   23.6444   2.04492   5.91111  100.0000   5.00000 80/09/18 81/10/27
                               TOT       18   11.1667   495.085   22.2505   1.99258   5.24449  100.0000   5.00000 80/09/18 81/11/06
CHROMIUM   CR.DISS   UG/L      K          3   9.99999   .000122   .011049   .001105   .006379   10.0000  10.00000 81/04/30 81/07/29
CHROMIUM   CR.TOT    UG/L                 9   26.6666   175.000   13.2287   .496078   4.40958   50.0000  10.00000 80/09/18 81/08/25
                               K         11   26.3636   65.4559   8.09048   .306881   2.43937   30.0000  10.00000 81/04/30 81/11/06
                               TOT       20   26.5000   108.158   10.3999   .392450   2.32549   50.0000  10.00000 80/09/18 81/11/06
COPPER     CU.DISS   UG/L                 1   40.0000                                           40.0000   40.0000 81/07/29 81/07/29
                               K          2  100.0000   .000000   .000000             .000000  100.0000  100.0000 81/04/30 81/05/29
                               TOT        3   80.0000   1200.00   34.6410   .433013   20.0000  100.0000   40.0000 81/04/30 81/07/29
COPPER     CU.TOT    UG/L                 9   107.778   1394.45   37.3424   .346476   12.4475   200.000   60.0000 80/09/18 81/10/26
                               K         11   99.9998   .018750   .136931   .001369   .041286  100.0000  100.0000 80/09/26 81/11/06
                               TOT       20   103.500   602.905   24.5541   .237238   5.49046   200.000   60.0000 80/09/18 81/11/06
IRON       FE.TOT    UG/L                20   5689.96  .283E+08   5322.87   .935484   1190.23   23000.0   1400.00 80/09/18 81/11/06
IRON       FE.DISS   UG/L                 3   266.666   3333.28   57.7346   .216505   33.3331   300.000   200.000 81/04/30 81/07/29
LEAD       PB.DISS   UG/L      K          3   20.0000   300.001   17.3205   .866027   10.0000   40.0000  10.00000 81/04/30 81/07/29
LEAD       PB.TOT    UG/L                16   63.4373   4365.69   66.0734   1.04155   16.5183   290.000   15.0000 80/09/26 81/11/06
                               K          4   9.99999   .000163   .012758   .001276   .006379  10.00000  10.00000 80/09/19 81/10/27
                               TOT       20   52.7498   3927.53   62.6700   1.18806   14.0134   290.000  10.00000 80/09/18 81/11/06
MANGNESE   MN        UG/L                20   284.998   22689.7   150.631   .528533   33.6821   610.000   70.0000 80/09/18 81/11/06
MANGNESE   MN.DISS   UG/L                 3   146.667   4133.35   64.2912   .438349   37.1185   220.000  100.0000 81/04/30 81/07/29
NICKEL     NI.TOTAL  UG/L                 2  100.0000   .000000   .000000             .000000  100.0000  100.0000 80/09/26 80/10/26
                               K          4   79.9999   1600.01   40.0001   .500002   20.0000  100.0000   20.0000 80/09/18 81/07/29
                               TOT        6   86.6666   1066.68   32.6601   .376848   13.3334  100.0000   20.0000 80/09/18 81/07/29
ZINC       ZN.DISS   UG/L                 3   33.3333   33.3345   5.77360   .173208   3.33339   40.0000   30.0000 81/04/30 81/07/29
ZINC       ZN.TOT    UG/L                20   114.500   8762.87   93.6102   .817558   20.9319   340.000   20.0000 80/09/18 81/11/06
TOT COLI   MPN CONF  TUBECODE            14   429.714   22565.2   150.217   .349575   40.1472   604.000   15.0000 80/09/26 81/10/27
                               L          1   638.000                                           638.000   638.000 81/05/29 81/05/29
                               TOT       15   443.600   23845.6   154.420   .348107   39.8712   638.000   15.0000 80/09/26 81/10/27
FEC COLI   MPN       TUBECODE            15   291.286   14486.4   120.359   .413199   31.0766   518.000   2.30000 80/09/26 81/10/27
FEC STRP   MPN-KFBR  TUBE CD             15   341.320   14030.8   118.452   .346533   30.5841   538.000   9.30000 80/09/26 81/10/27
TOT FLOW   COMPOSIT  1000GALS            19   3310.74  .123E+09   11123.6   3.35985   2551.93   49140.0   174.000 80/09/18 81/11/06
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TABLE 7

STORMWATER RUNOFF COMPOSITE SAMPLING DATA

2-PTE/DNPETTEBK 2-PTE
43 08 06.0 070 55 33.0 4
DNSTREAM/PETTEE BK/SOURCE MONITOR/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 CLASS 04 CSN-RSP 0590867-2754310

PARAMETER			RMK	NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
TURB	TRBIDMTR	HACH FTU		11	54.1363	2424.31	49.2372	.909504	14.8456	150.000	8.50000	81/04/30	81/11/06
CNDUCTVY	AT 25C	MICROMHO		18	206.333	16023.2	126.583	.613487	29.8358	669.000	72.0000	80/09/18	81/11/06
PRECIP	DURATION	MINUTES		19	551.052	212721	461.217	.836975	105.810	1620.00	45.0000	80/09/18	81/11/06
DRY DAYS	PRECEDNG	PRECIP		19	5.47368	12.9298	3.59581	.656927	.824935	15.0000	1.00000	80/09/18	81/11/06
BOD	5 DAY	MG/L		15	18.9533	488.196	22.0952	1.16577	5.70495	95.0000	3.80000	80/09/18	81/10/02
COD	HI LEVEL	MG/L		19	58.2842	877.153	29.6168	.508144	6.79455	132.000	24.0000	80/09/18	81/11/06
LAB	PH	SU		17	6.79999	.061264	.247516	.036399	.060031	7.10000	6.30000	80/09/18	81/10/27
T ALK	CACO3	MG/L		11	29.1545	32.1226	5.66768	.194402	1.70887	37.2000	21.0000	81/05/29	81/10/27
RESIDUE	TOTAL	MG/L		19	232.158	19764.4	140.586	.605562	32.2526	652.000	31.0000	80/09/18	81/11/06
RESIDUE	TOT VOL	MG/L		14	67.0714	633.765	25.1747	.375342	6.72822	116.000	20.0000	81/04/30	81/11/06
RESIDUE	TOT NFLT	MG/L		18	111.028	17380.8	131.836	1.18742	31.0741	592.000	6.00000	80/09/18	81/11/06
RESIDUE	VOL NFLT	MG/L		14	23.0000	848.308	29.1257	1.26634	7.78417	114.000	3.00000	81/04/30	81/11/06
NH3+NH4-	N TOTAL	MG/L		6	.178333	.015777	.125605	.704329	.051278	.420000	.050000	80/10/19	81/10/07
			K	11	.100000	.172E-07	.000134	.001337	.000040	.100000	.100000	80/09/18	81/11/06
			TOT	17	.127647	.006419	.080119	.627665	.019432	.420000	.050000	80/09/18	81/11/06
TOT KJEL	N	MG/L		15	1.26333	.246257	.496243	.392805	.128129	2.10000	.000000	80/10/19	81/11/06
NO2&NO3	N-TOTAL	MG/L		17	.580588	.059343	.243605	.419583	.059083	.990000	.210000	80/09/18	81/11/06
			K	1	.050000					.050000	.050000	80/10/26	80/10/26
			TOT	18	.551111	.071493	.267381	.485168	.063022	.990000	.050000	80/09/18	81/11/06
ORTHOPO4	PO4	MG/L		18	.015178	.000655	.025588	1.68587	.006031	.115000	.000200	80/09/18	81/11/06
			K	1	.001000					.001000	.001000	81/09/19	81/09/19
			TOT	19	.014432	.000629	.025079	1.73776	.005753	.115000	.000200	80/09/18	81/11/06
PHOS-TOT		MG/L P		16	.160875	.015277	.123600	.768297	.030900	.500000	.040000	80/09/26	81/11/06
			L	1	.400000					.400000	.400000	80/09/18	80/09/18
			TOT	17	.174941	.017686	.132987	.760185	.032254	.500000	.040000	80/09/18	81/11/06
MGNSIUM	MG.DISS	MG/L		4	2.25000	.330002	.574458	.255315	.287229	2.60000	1.40000	81/04/30	81/07/29
MGNSIUM	MG.TOT	MG/L		20	3.05149	1.95822	1.39937	.458584	.312908	6.30000	.600000	80/09/18	81/11/06
SODIUM	NA.TOT	MG/L		16	23.0500	514.387	22.6801	.983953	5.67002	102.000	6.00000	80/09/18	81/11/06
SODIUM	NA.DISS	MG/L		2	14.9500	18.6052	4.31338	.288520	3.05002	18.0000	11.9000	81/05/29	81/07/29
PTSSIUM	K.DISS	MG/L		2	3.45000	.404999	.636395	.184462	.449999	3.90000	3.00000	81/05/29	81/07/29
PTSSIUM	K.TOT	MG/L		13	4.07230	2.07033	1.43887	.353330	.399069	8.54000	2.80000	80/09/26	81/10/27
CHLORIDE	TOTAL	MG/L		19	398.489	2633759	1622.89	4.07260	372.315	7100.00	7.60000	80/09/18	81/11/06
CADMIUM	CD.DISS	UG/L	K	3	5.00000	.000000	.000000		.000000	5.00000	5.00000	81/04/30	81/07/29
CADMIUM	CD.TOT	UG/L		4	5.49999	1.00007	1.00004	.181825	.500018	7.00000	5.00000	81/08/16	81/11/06
			K	14	6.07141	4.53296	2.12907	.350672	.569019	10.00000	5.00000	80/09/18	81/10/27
			TOT	18	5.94443	3.70261	1.92422	.323701	.453542	10.00000	5.00000	80/09/18	81/11/06
CHROMIUM	CR.DISS	UG/L		2	9.99999	.000214	.014616	.001462	.010335	10.00000	10.00000	81/05/17	81/05/29
			K	2	9.99999	.000259	.016106	.001611	.011389	10.0000	10.00000	81/04/30	81/07/29
			TOT	4	9.99999	.000163	.012758	.001276	.006379	10.0000	10.00000	81/04/30	81/07/29
CHROMIUM	CR.TOT	UG/L		10	23.0000	89.9991	9.48679	.412469	2.99999	40.0000	10.00000	80/09/18	81/10/26
			K	10	29.9999	.001736	.041667	.001389	.013176	30.0000	30.0000	81/07/29	81/11/06
CHROMIUM	CR.TOT	UG/L	TOT	20	26.5000	55.5267	7.45162	.281194	1.66623	40.0000	10.00000	80/09/18	81/11/06
COPPER	CU.DISS	UG/L		2	70.0000	1800.00	42.4264	.606092	30.0000	100.0000	40.0000	81/05/29	81/07/29
			K	2	100.0000	.000000	.000000		.000000	100.0000	100.0000	81/04/30	81/05/17
			TOT	4	84.9999	900.010	30.0002	.352943	15.0001	100.0000	40.0000	81/04/30	81/07/29
COPPER	CU.TOT	UG/L		14	94.2853	210.995	14.5257	.154060	3.88215	100.0000	60.0000	80/09/18	81/10/07
			K	5	99.9998	.039062	.197642	.001976	.088388	100.0000	100.0000	80/11/25	81/11/06
			TOT	19	95.7893	159.076	12.6125	.131670	2.89352	100.0000	60.0000	80/09/18	81/11/06
IRON	FE.TOT	UG/L		20	4900.47	.142E+08	3776.27	.770594	844.400	16000.0	1000.00	80/09/18	81/11/06
IRON	FE.DISS	UG/L		4	225.000	2500.00	50.0000	.222222	25.0000	300.000	200.000	81/04/30	81/07/29
LEAD	PB.DISS	UG/L	K	4	17.5000	225.001	15.0000	.857145	7.50001	40.0000	10.00000	81/04/30	81/07/29
LEAD	PB.TOT	UG/L		17	92.6468	10494.1	102.441	1.10571	24.8455	450.000	10.00000	80/09/26	81/11/06
			K	3	20.0000	300.001	17.3205	.866027	10.0000	40.0000	10.00000	80/09/18	81/07/29
			TOT	20	81.7498	9577.01	97.8622	1.19709	21.8826	450.000	10.00000	80/09/18	81/11/06
MANGNESE	MN	UG/L		20	430.997	64653.2	254.270	.589957	56.8565	980.000	60.0000	80/09/18	81/11/06
MANGNESE	MN.DISS	UG/L		4	77.4999	2091.68	45.7348	.590128	22.8674	140.000	30.0000	81/04/30	81/07/29
NICKEL	NI.TOTAL	UG/L		3	83.3333	833.334	28.8675	.346410	16.6667	100.0000	50.0000	80/09/18	80/11/25
			K	2	60.0000	3200.00	56.5685	.942809	40.0000	100.0000	20.0000	80/10/26	81/07/29
			TOT	5	73.9999	1380.01	37.1485	.502007	16.6133	100.0000	20.0000	80/09/18	81/07/29
ZINC	ZN.DISS	UG/L		4	37.5000	91.6680	9.57434	.255316	4.78717	50.0000	30.0000	81/04/30	81/07/29
ZINC	ZN.TOT	UG/L		20	126.000	3351.58	57.8928	.459468	12.9452	270.000	40.0000	80/09/18	81/11/06
TOT COLI	MPN CONF	TUBECODE		14	446.214	15977.5	126.402	.283277	33.7824	536.000	23.0000	80/09/26	81/10/27
FEC COLI	MPN	TUBECODE		14	379.000	25714.0	160.356	.423102	42.8569	900.000	232.000	80/09/26	81/10/27
FEC STRP	MPN-KFBR	TUBE CD		13	387.715	17831.7	133.535	.344416	37.0360	536.000	2.30000	80/09/26	81/10/27
			K	1	248.000					248.000	248.000	81/05/29	81/05/29
			TOT	14	377.735	17854.3	133.620	.353740	35.7114	536.000	2.30000	80/09/26	81/10/27
TOT FLOW	COMPOSIT	1000GALS		19	1356.89	2198119	1482.61	1.09265	340.133	5210.00	399.000	80/09/18	81/11/06
PRECIPIT	ATION	IN/STORM		19	.620526	.305605	.552816	.890882	.126825	2.67000	.200000	80/09/18	81/11/06

STORMWATER RUNOFF COMPOSITE SAMPLING DATA

TABLE 8

7-OYS/UPOYSTER 7-OYS
43 07 57.0 070 56 27.0 4
UPSTREAM/OYSTER R/BACKGROUND/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 610509
0000 CLASS 04 CSN-RSP 0590873-2954316

PARAMETER			RMK	NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
TURB	TRBIDMTR	HACH FTU		15	7.59333	9.63208	3.10356	.408722	.801336	14.0000	.000000	81/05/01	81/10/29
CNDUCTVY	AT 25C	MICROMHO		21	162.373	894.937	29.9155	.184239	6.52810	214.000	110.000	80/11/27	81/12/05
PRECIP	DURATION	MINUTES		21	842.143	592814	769.944	.914268	168.016	2760.00	30.0000	80/11/27	81/12/05
DRY DAYS	PRECEDNG	PRECIP		21	5.28571	8.11429	2.84856	.538917	.621607	11.0000	2.00000	80/11/27	81/12/05
BOD	5 DAY	MG/L		20	7.28000	57.3017	7.56979	1.03981	1.69266	32.0000	.400000	80/11/27	81/12/05
COD	HI LEVEL	MG/L		20	46.9050	4575.31	67.6410	1.44209	15.1250	332.000	19.6000	80/11/27	81/12/05
LAB	PH	SU		20	7.02499	.051449	.226825	.032288	.050720	7.40000	6.60000	80/11/27	81/12/05
T ALK	CACO3	MG/L		16	23.7000	27.1036	5.20612	.219668	1.30153	29.6000	12.0000	81/06/11	81/12/05
RESIDUE	TOTAL	MG/L		21	115.143	1214.03	34.8430	.302606	7.60336	194.000	16.0000	80/11/27	81/12/05
RESIDUE	TOT VOL	MG/L		20	55.1500	525.714	22.9284	.415747	5.12696	105.000	2.00000	81/05/01	81/12/05
RESIDUE	TOT NFLT	MG/L		19	12.2105	985.064	31.3857	2.57038	7.20038	140.000	1.00000	80/11/27	81/12/05
			K	2	1.00000	.000000	.000000		.000000	1.00000	1.00000	81/05/01	81/06/22
			TOT	21	11.1429	897.928	29.9654	2.68921	6.53900	140.000	1.00000	80/11/27	81/12/05
RESIDUE	VOL NFLT	MG/L		11	4.36364	18.6545	4.31909	.989791	1.30225	12.0000	1.00000	81/06/11	81/12/05
			K	7	1.00000	.000000	.000000		.000000	1.00000	1.00000	81/05/01	81/10/19
			TOT	18	3.05556	13.8203	3.71756	1.21666	.876238	12.0000	1.00000	81/05/01	81/12/05
NH3+NH4-	N TOTAL	MG/L		4	.162500	.021692	.147281	.906344	.073640	.360000	.010000	81/07/30	81/12/05
			K	16	.100000	.357E-07	.000189	.001891	.000047	.100000	.100000	81/05/01	81/11/07
			TOT	20	.112500	.004083	.063898	.567982	.014288	.360000	.010000	81/05/01	81/12/05
TOT KJEL	N	MG/L		20	1.00056	.107462	.327814	.327651	.073301	1.80000	.560000	80/11/27	81/11/07
NO2&NO3	N-TOTAL	MG/L		20	.355500	.017194	.131128	.368854	.029321	.740000	.210000	80/11/27	81/12/05
ORTHOPO4	PO4	MG/L		18	.014444	[illegible]	.036590	2.53318	.008624	.159000	.001000	80/11/27	81/12/05
			K	1	.001000					.001000	.001000	81/07/21	81/07/21
			TOT	19	.013737	.001274	.035693	2.59834	.008189	.159000	.001000	80/11/27	81/12/05
PHOS-TOT		MG/L P		21	.060905	.001434	.037868	.621761	.008263	.200000	.021000	80/11/27	81/12/05
MGNSIUM	MG.DISS	MG/L		7	2.64285	.188698	.434394	.164365	.164185	3.15000	1.80000	81/05/01	81/07/30
MGNSIUM	MG.TOT	MG/L		22	2.73090	.512188	.715673	.262065	.152582	4.20000	1.15000	80/11/27	81/12/05
SODIUM	NA.TOT	MG/L		22	13.7818	5.46187	2.33706	.169576	.498264	17.0000	8.00000	80/11/27	81/12/05
SODIUM	NA.DISS	MG/L		7	13.6000	3.20341	1.78981	.131603	.676484	15.0000	10.0000	81/05/01	81/07/30
PTSSIUM	K.DISS	MG/L		7	1.30714	.137024	.370167	.204836	.139910	2.30000	1.40000	81/05/01	81/07/30
PTSSIUM	K.TOT	MG/L		20	2.48000	1.62801	1.27593	.514491	.285308	7.50000	1.40000	81/05/01	81/12/05
CHLORIDE	TOTAL	MG/L		21	29.2857	50.3150	7.09331	.242211	1.54789	41.0000	16.0000	80/11/27	81/12/05
CADMIUM	CD.DISS	UG/L	K	7	4.99999	.000061	.007812	.001563	.002953	5.00000	5.00000	81/05/01	81/07/30
CADMIUM	CD.TOT	UG/L		2	6.00000	-.152E-04	.000000		.000000	6.00000	6.00000	81/06/11	81/07/30
			K	20	5.24999	1.24999	1.11803	.212958	.249999	10.00000	5.00000	80/11/27	81/12/05
			TOT	22	5.31817	1.17964	1.08611	.204227	.231560	10.00000	5.00000	80/11/27	81/12/05
CHROMIUM	CR.DISS	UG/L		1	10.00000					10.00000	10.00000	81/07/07	81/07/07
			K	6	9.99999	.000146	.012103	.001210	.004941	10.0000	10.00000	81/05/01	81/07/30
			TOT	7	9.99999	.000163	.012758	.001276	.004822	10.0000	10.00000	81/05/01	81/07/30
CHROMIUM	CR.TOT	UG/L		6	20.0000	160.000	12.6491	.632456	5.16398	40.0000	10.00000	80/11/27	81/12/05
			K	16	23.7499	91.6682	9.57435	.403132	2.39359	30.0000	10.00000	81/06/11	81/11/07
CHROMIUM	CR.TOT	UG/L	TOT	22	22.7272	106.495	10.3196	.454066	2.20016	40.0000	10.00000	80/11/27	81/12/05
COPPER	CU.DISS	UG/L	K	7	88.5713	914.311	30.2376	.341392	11.4287	100.0000	20.0000	81/05/01	81/07/30
COPPER	CU.TOT	UG/L		2	100.0000	.000000	.000000		.000000	100.0000	100.0000	81/07/30	81/10/07
			K	20	95.9998	320.003	17.8886	.186340	4.00002	100.0000	20.0000	80/11/27	81/12/05
			TOT	22	96.3634	290.911	17.0561	.176998	3.63637	100.0000	20.0000	80/11/27	81/12/05
IRON	FE.TOT	UG/L		21	1267.14	1114891	1055.88	.833281	230.413	5500.00	100.0000	80/11/27	81/12/05
IRON	FE.DISS	UG/L		6	590.000	54999.8	234.520	.397492	95.7425	800.000	200.000	81/05/01	81/07/30
LEAD	PB.DISS	UG/L	K	7	14.2857	128.572	11.3389	.793727	4.28572	40.0000	10.00000	81/05/01	81/07/30
LEAD	PB.TOT	UG/L		6	19.8333	100.567	10.0283	.505629	4.09404	35.0000	10.00000	81/06/11	81/10/04
			K	16	11.8750	56.2501	7.50001	.631580	1.87500	40.0000	10.00000	80/11/27	81/12/05
			TOT	22	14.0454	77.2840	8.79113	.625907	1.87428	40.0000	10.00000	80/11/27	81/12/05
MANGNESE	MN	UG/L		22	97.2271	4915.80	70.1127	.721124	14.7481	380.000	30.0000	80/11/27	81/12/05
MANGNESE	MN.DISS	UG/L		7	29.2857	470.237	21.6849	.740462	8.19614	70.0000	10.00000	81/05/01	81/07/30
NICKEL	NI.TOTAL	UG/L	K	2	60.0000	3200.00	56.5685	.942809	40.0000	100.0000	20.0000	80/11/27	81/07/30
ZINC	ZN.DISS	UG/L		7	71.4285	3414.30	58.4320	.818049	22.0852	170.000	20.0000	81/05/01	81/07/30
ZINC	ZN.TOT	UG/L		22	80.8180	5277.57	72.6469	.898895	15.4884	370.000	10.00000	80/11/27	81/12/05
TOT COLI	MPN CONF	TUBECODE		17	304.706	12638.2	112.420	.368946	27.2658	563.000	160.000	81/05/01	81/12/05
FEC COLI	MPN	TUBECODE		11	767.454	8034.79	89.6370	.335149	27.0266	436.000	148.000	81/07/07	81/12/05
			K	6	181.333	2666.69	51.6400	.284779	21.0819	248.000	148.000	81/05/01	81/10/07
			TOT	17	237.059	7654.69	87.4911	.369069	21.2197	436.000	148.000	81/05/01	81/12/05
FEC STRP	MPN-KFBR	TUBE CD		15	298.666	7855.57	88.6316	.296758	22.8846	463.000	160.000	81/05/01	81/12/05
			K	2	248.000	.000000	.000000		.000000	248.000	248.000	81/06/27	81/07/14
			TOT	17	292.706	7156.75	84.5976	.289019	20.5179	463.000	160.000	81/05/01	81/12/05
TOT FLOW	COMPOSIT	1000GALS		21	25365.0	.152E+10	39042.3	1.53922	8519.73	165683	1535.00	80/11/27	81/12/05

TABLE 9

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STORMWATER RUNOFF COMPOSITE SAMPLING DATA            5-OYS/DNOYSTER  5-OYS
                                                     43 07 50.0 070 55 11.0  4
                                                     DNSTREAM/OYSTER R/SOURCE MONITOR/DURHAM NH
                                                     33017 NEW HAMPSHIRE      STRAFFORD
                                                     NORTH ATLANTIC           021000
                                                     PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
                                                     22NHCITY  810509
                                                      0000  CLASS 04 CSN-RSP 0590872-2954315

PARAMETER

                                  RMK  NUMBER     MEAN  VARIANCE  STAN DEV  COEF VAR  STAND ER   MAXIMUM   MINIMUM  BEG DATE END DATE
  TURB     TRBIDMTR   HACH FTU             15  8.47199   19.0917   4.36941   .515747   1.12818   21.1000   .560000  81/05/02 81/11/08
CNDUCTVY    AT 25C    MICROMHO             19  182.474   1050.38   32.4095   .177612   7.43526   233.000   120.000  80/11/27 81/12/05
 PRECIP    DURATION    MINUTES             19  881.842    633989   796.234   .902921   182.669   2760.00   30.0000  80/11/27 81/12/05
DRY DAYS   PRECEDNG    PRECIP              19  5.05263   8.38597   2.89585   .573139   .664354   11.0000   2.00000  80/11/27 81/12/05
  BOD        5 DAY      MG/L               16  5.70625   22.2326   4.71515   .826313   1.17879   21.0000   1.20000  80/11/27 81/12/05
  COD      HI LEVEL     MG/L               19  36.1158   250.986   15.8425   .438660   3.63453   92.0000   12.0000  80/11/27 81/12/05
  LAB         PH         SU                18  7.07222   .030345   .174199   .024631   .041059   7.40000   6.80000  80/11/27 81/12/05
 T ALK      CACO3       MG/L               14  27.7571   36.9267   6.07673   .218925   1.62407   38.2000   14.8000  81/06/12 81/12/05
RESIDUE     TOTAL       MG/L               19  128.316   600.455   24.5042   .190968   5.62164   170.000   89.0000  80/11/27 81/12/05
RESIDUE    TOT VOL      MG/L               17  64.0000   300.250   17.3277   .270746   4.20259   99.0000   32.0000  81/05/02 81/12/05
RESIDUE    TOT NFLT     MG/L               14  10.5000   79.5000   8.91628   .849169   2.38297   35.0000   3.00000  80/11/27 81/12/05
                                  K         4  1.00000   .000000   .000000             .000000   1.00000   1.00000  81/05/02 81/10/05
                                  TOT      18  8.38889   77.3105   8.79264   1.04813   2.07244   35.0000   1.00000  80/11/27 81/12/05
RESIDUE    VOL NFLT     MG/L               10  4.20000   11.7333   3.42540   .815571   1.08320   12.0000   1.00000  81/06/12 81/11/09
                                  K         7  1.00000   .000000   .000000             .000000   1.00000   1.00000  81/05/02 81/12/05
                                  TOT      17  2.88235   9.23530   3.03896   1.05433   .737057   12.0000   1.00000  81/05/02 81/12/05
NH3+NH4-    N TOTAL     MG/L                4  .165000   .004100   .064031   .388068   .032016   .260000   .120000  81/06/28 81/12/05
                                  K        14  .100000  .412E-07   .000203   .002031   .000054   .100000   .100000  81/05/02 81/11/08
                                  TOT      18  .114444   .001497   .038688   .338052   .009119   .260000   .100000  81/05/02 81/12/05
TOT KJEL       N        MG/L               18  .913888   .045674   .213715   .233852   .050373   1.20000   .450000  80/11/27 81/11/09
NO2&NO3     N-TOTAL     MG/L               19  .276789   .010345   .101709   .367462   .023334   .450000   .102000  80/11/27 81/12/05
ORTHOPO4      PO4       MG/L               18  .013944   .000165   .012831   .920179   .003024   .044000   .002000  80/11/27 81/12/05
                                  K         1  .001000                                           .001000   .001000  81/06/23 81/06/23
                                  TOT      19  .013263   .000164   .012819   .966481   .002941   .044000   .001000  80/11/27 81/12/05
PHOS-TOT                MG/L P             19  .070579   .000637   .025244   .357674   .005791   .122000   .031000  80/11/27 81/12/05
MGNSIUM     MG,DISS     MG/L                7  2.65714   .190361   .436304   .164200   .164907   3.10000   1.90000  81/05/02 81/07/30
MGNSIUM     MG,TOT      MG/L               20  2.93949   .275309   .524699   .178500   .117326   4.17000   2.10000  80/11/27 81/12/05
SODIUM      NA,TOT      MG/L               19  15.7263   10.3171   3.21202   .204245   .736887   23.0000   8.00000  80/11/27 81/12/05
 SODIUM     NA,DISS     MG/L                6  17.1333   9.40273   3.06639   .178972   1.25185   23.0000   15.0000  81/06/12 81/07/30
PTSSIUM      K,DISS     MG/L                6  2.42333   .224866   .474200   .195681   .193591   3.00000   1.64000  81/06/12 81/07/30
PTSSIUM     K,TOT       MG/L               17  2.83176   .282170   .531197   .187565   .128834   3.70000   1.80000  81/06/12 81/12/05
CHLORIDE     TOTAL      MG/L               19  29.8368   62.7072   7.91879   .265403   1.81669   40.0000   12.0000  80/11/27 81/12/05
CADMIUM     CD,DISS     UG/L      K         7  4.99999   .000061   .007812   .001563   .002953   5.00000   5.00000  81/05/02 81/07/30
CADMIUM     CD,TOT      UG/L                2  11.0000   2.00021   1.41429   .128572   1.00005   12.0000  10.00000  81/11/08 81/12/05
                                  K        18  5.27776   1.38889   1.17851   .223297   .277778  10.00000   5.00000  80/11/27 81/10/26
                                  TOT      20  5.84999   4.45001   2.10951   .360600   .471700   12.0000   5.00000  80/11/27 81/12/05
CHROMIUM    CR,DISS     UG/L      K         7  9.99999   .000163   .012758   .001276   .004822   10.0000  10.00000  81/05/02 81/07/30
CHROMIUM    CR,TOT      UG/L                5  16.0000   180.000   13.4164   .838526   6.00000   40.0000  10.00000  80/11/27 81/07/15
                                  K        15  23.3333   95.2397   9.75908   .418247   2.51978   30.0000  10.00000  81/06/12 81/12/05
                                  TOT      20  21.4999   118.685   10.8943   .506712   2.43603   40.0000  10.00000  80/11/27 81/12/05
COPPER      CU.DISS     UG/L                1  100.0000                                          100.0000  100.0000  81/06/23 81/06/23
COPPER      CU.DISS     UG/L      K         6  86.6665   1066.69   32.6603   .376850   13.3335  100.0000   20.0000  81/05/02 81/07/30
                                  TOT       7  88.5713   914.311   30.2376   .341392   11.4287  100.0000   20.0000  81/05/02 81/07/30
COPPER      CU,TOT      UG/L                1  100.0000                                          100.0000  100.0000  81/06/23 81/06/23
                                  K        19  95.7893   336.847   18.3534   .191602   4.21056  100.0000   20.0000  80/11/27 81/12/05
                                  TOT      20  95.9998   320.003   17.8886   .186340   4.00002  100.0000   20.0000  80/11/27 81/12/05
  IRON      FE,TOT      UG/L               19  1187.37   87221.3   295.333   .248729   67.7539   1700.00   600.000  80/11/27 81/12/05
  IRON      FE,DISS     UG/L                7  599.999   19867.3   140.952   .234919   53.2747   800.000   340.000  81/05/02 81/07/30
  LEAD      PB,DISS     UG/L                1  12.0000                                           12.0000   12.0000  81/06/12 81/06/12
                                  K         6  15.0000   150.000   12.2475   .816498   5.00000   40.0000  10.00000  81/05/02 81/07/30
                                  TOT       7  14.5714   126.286   11.2377   .771216   4.24745   40.0000  10.00000  81/05/02 81/07/30
LEAD        PB,TOT      UG/L                7  39.2856   4726.57   68.7500   1.75000   25.9851   195.000  10.00000  81/06/12 81/11/08
                                  K        13  12.3077   69.2309   8.32051   .676042   2.30769   40.0000  10.00000  80/11/27 81/12/05
                                  TOT      20  21.7500   1710.62   41.3596   1.90159   9.24829   195.000  10.00000  80/11/27 81/12/05
MANGNESE       MN       UG/L               19  86.7893   991.399   31.4865   .362792   7.22350   150.000   40.0000  80/11/27 81/12/05
MANGNESE    MN,DISS     UG/L                6  28.3333   376.666   19.4079   .684984   7.92323   60.0000  10.00000  81/05/02 81/07/30
 NICKEL     NI,TOTAL    UG/L                1  100.0000                                          100.0000  100.0000  80/11/27 80/11/27
                                  K         1  20.0000                                           20.0000   20.0000  81/07/30 81/07/30
                                  TOT       2  60.0000   3200.00   56.5685   .942809   40.0000  100.0000   20.0000  80/11/27 81/07/30
  ZINC      ZN,DISS     UG/L                7  54.2857   461.909   21.4921   .395907   8.12324   80.0000   30.0000  81/05/02 81/07/30
ZINC        ZN,TOT      UG/L               20  68.2998   8520.94   92.3089   1.35152   20.6409   450.000   10.0000  80/11/27 81/12/05
TOT COLI   MPN CONF   TUBECODE             15  408.200   5314.07   72.8977   .178583   18.8221   538.000   263.000  81/05/02 81/12/05
FEC COLI      MPN     TUBECODE             12  290.916   3010.73   54.8701   .188611   15.8396   363.000   186.000  81/05/02 81/12/05
                                  K         3  229.333   1045.37   32.3323   .140984   18.6670   248.000   192.000  81/06/23 81/09/21
                                  TOT      15  278.600   3165.14   56.2596   .201937   14.5262   363.000   186.000  81/05/02 81/12/05
FEC STRP   MPN-KFBR    TUBE CD             14  307.286   3758.23   61.3044   .199503   16.3843   366.000   148.000  81/05/02 81/12/05
                                  K         1  152.000                                           152.000   152.000  81/09/21 81/09/21
                                  TOT      15  296.933   5097.42   71.3963   .240446   18.4344   366.000   148.000  81/05/02 81/12/05
TOT FLOW   COMPOSIT   1000GALS             19  75570.4  .324E+10   56931.0   .753350   13060.9    231598   9999.00  80/11/27 81/12/05
PRECIPIT   ATION      IN/STORM             19  .869473   .274706   .524124   .602806   .120242   2.10000   .250000  80/11/27 81/12/05
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TABLE 10

STORMWATER RUNOFF COMPOSITE SAMPLING DATA

1-PKG/PARKINLOT 1-PKG
43 07 59.0 070 55 39.0 4
SHOP-SAVE/COMMERCIAL PARKING LOT/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 CLASS 04 CSN-RSF 0590866-2954309

PARAMETER			RMK	NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM	BEG DATE	END DATE
TURB	TRBIDMTR	HACH FTU		11	27.3000	586.502	24.2178	.887100	7.30194	76.0000	2.10000	81/04/25	81/07/13
CNDUCTVY	AT 25C	MICROMHO		29	71.7413	5768.71	75.9520	1.05869	14.1039	412.000	18.1000	80/07/29	81/10/06
PRECIP	DURATION	MINUTES		34	679.088	2961664	1720.95	2.53420	295.140	9999.00	30.0000	80/07/17	81/10/06
DRY DAYS	PRECEDNG	PRECIP		34	4.55147	11.4007	3.37649	.741846	.579064	15.0000	.750000	80/07/17	81/10/06
BOD	5 DAY	MG/L		33	16.1151	113.752	10.6655	.661829	1.85662	48.0000	1.40000	80/07/17	81/10/02
COD	HI LEVEL	MG/L		33	97.0666	4293.07	65.5215	.675015	11.4058	330.000	24.0000	80/07/17	81/10/06
LAB	PH	SU		31	4.71290	.497811	.705557	.149708	.126722	7.50000	4.00000	80/07/17	81/10/06
T ALK	CACO3	MG/L		9	18.3000	2088.85	45.7039	2.49748	15.2346	140.000	.000000	81/06/04	81/09/16
			K	8	4.50000	.000000	.000000		.000000	4.50000	4.50000	81/05/29	81/10/06
			TOT	17	11.8059	1094.83	33.0883	2.80269	8.02508	140.000	.000000	81/05/29	81/10/06
RESIDUE	TOTAL	MG/L		33	108.624	4300.40	65.5774	.603709	11.4156	256.000	3.00000	80/07/17	81/10/06
RESIDUE	TOT VOL	MG/L		22	62.0000	1880.10	43.3601	.699356	9.24440	188.000	5.00000	81/04/25	81/10/06
			K	1	1.00000					1.00000	1.00000	81/08/16	81/08/16
			TOT	23	59.3478	1956.42	44.2314	.745292	9.22289	188.000	1.00000	81/04/25	81/10/06
RESIDUE	TOT NFLT	MG/L		31	61.3774	2389.74	48.8850	.796466	8.78001	191.000	2.00000	80/07/17	81/10/06
			K	1	1.00000					1.00000	1.00000	81/07/29	81/07/29
			TOT	32	59.4906	2426.57	49.2603	.828034	8.70807	191.000	1.00000	80/07/17	81/10/06
RESIDUE	VOL NFLT	MG/L		19	36.7368	1035.09	32.1729	.875766	7.38096	106.000	4.00000	81/04/25	81/09/24
			K	2	1.00000	.000000	.000000		.000000	1.00000	1.00000	81/07/29	81/08/16
			TOT	21	33.3333	1047.13	32.3594	.970784	7.06141	106.000	1.00000	81/04/25	81/09/24
NH3+NH4-	N TOTAL	MG/L		24	.739582	1.68005	1.29617	1.75257	.264579	6.00000	.010000	80/07/17	81/10/06
			K	5	.100000	-.279E-08	.000000		.000000	.100000	.100000	80/09/02	81/06/20
			TOT	29	.629309	1.44049	1.20020	1.90718	.222872	6.00000	.010000	80/07/17	81/10/06
TOT KJEL	N	MG/L		18	2.09000	1.64926	1.28423	.614468	.302697	4.80000	.630000	81/04/25	81/10/06
NO2&NO3	N-TOTAL	MG/L		28	.770712	.294029	.542245	.703563	.102475	2.60000	.070000	80/07/29	81/10/06
ORTHOPO4	PO4	MG/L		22	.053000	.008429	.091810	1.73227	.019574	.433000	.000000	80/08/05	81/10/06
			K	5	.001000	.159E-11	.000001	.001262	.564E-06	.001000	.001000	81/06/09	81/07/21
			TOT	27	.043370	.007232	.085040	1.96080	.016366	.433000	.000000	80/08/05	81/10/06
PHOS-TOT		MG/L P		26	.257807	.066036	.256975	.996772	.050397	.990000	.022000	80/07/29	81/10/06
			L	1	.340000					.340000	.340000	80/09/02	80/09/02
			TOT	27	.260851	.063747	.252481	.967911	.048590	.990000	.022000	80/07/29	81/10/06
MGNSIUM	MG.DISS	MG/L		15	.470000	.401271	.633460	1.34779	.163559	2.70000	.150000	81/04/25	81/07/29
MGNSIUM	MG.TOT	MG/L		35	.913710	.364091	.603399	.660384	.101993	2.80000	.240000	80/07/17	81/10/06
SODIUM	NA.TOT	MG/L		32	3.56000	8.97099	2.99516	.841338	.529475	17.0000	1.00000	80/07/17	81/10/06
SODIUM	NA.DISS	MG/L		13	3.64615	21.1393	4.59775	1.26099	1.27519	18.1000	1.00000	81/05/29	81/07/29
PTSSIUM	K.DISS	MG/L		13	1.11538	.981411	.990662	.888180	.274760	4.00000	.400000	81/05/29	81/07/29
PTSSIUM	K.TOT	MG/L		24	2.15416	10.8539	3.29452	1.52937	.672492	17.0000	.500000	81/05/29	81/10/06
CHLORIDE	TOTAL	MG/L		21	7.14714	44.3754	6.66148	.932049	1.45365	22.0000	1.90000	80/08/15	81/10/06
			K	7	2.28571	.571431	.755931	.330720	.285715	4.00000	2.00000	81/04/25	81/08/09
			TOT	28	5.93178	37.5930	6.13132	1.03364	1.15871	22.0000	1.90000	80/08/15	81/10/06
CADMIUM	CD.DISS	UG/L		3	7.99999	19.0002	4.35893	.544866	2.51663	13.0000	5.00000	81/05/29	81/07/05
CADMIUM	CD.DISS	UG/L	K	12	4.99999	.000067	.008160	.001632	.002356	5.00000	5.00000	81/04/25	81/07/29
			TOT	15	5.59999	4.25720	2.06330	.368447	.532742	13.0000	5.00000	81/04/25	81/07/29
CADMIUM	CD.TOT	UG/L		7	6.85713	8.47624	2.91140	.424580	1.10040	12.0000	5.00000	80/10/19	81/10/06
			K	23	5.43477	2.07507	1.44051	.265055	.300367	10.00000	5.00000	80/08/15	81/09/24
			TOT	30	5.76665	3.70228	1.92413	.333665	.351297	12.0000	5.00000	80/08/15	81/10/06
CHROMIUM	CR.DISS	UG/L		7	11.4286	14.2858	3.77966	.330720	1.42858	20.0000	10.00000	81/04/29	81/07/29
			K	8	9.99999	.000105	.010229	.001023	.003616	10.0000	10.00000	81/04/25	81/07/29
			TOT	15	10.6667	6.66676	2.58201	.242063	.666672	20.0000	10.00000	81/04/25	81/07/29
CHROMIUM	CR.TOT	UG/L		20	22.7499	140.726	11.8628	.521443	2.65260	50.0000	10.00000	80/07/17	81/08/25
			K	13	22.3076	102.565	10.1274	.453989	2.80884	30.0000	10.00000	81/04/25	81/10/06
			TOT	33	22.5757	122.066	11.0483	.489391	1.92327	50.0000	10.00000	80/07/17	81/10/06
COPPER	CU.DISS	UG/L		10	95.9998	160.021	12.6499	.131770	4.00026	100.000	60.0000	81/04/25	81/07/29
			K	5	99.9998	.039062	.197642	.001976	.088388	100.0000	100.0000	81/06/09	81/07/21
			TOT	15	97.3332	106.687	10.3290	.106120	2.66693	100.000	60.0000	81/04/25	81/07/29
COPPER	CU.TOT	UG/L		29	99.8963	719.596	26.8253	.268531	4.98133	200.000	10.00000	80/07/17	81/10/06
			K	4	99.9999	.027344	.165359	.001654	.082680	100.0000	100.0000	81/07/05	81/09/16
			TOT	33	99.9089	629.648	25.0928	.251157	4.36810	200.000	10.00000	80/07/17	81/10/06
IRON	FE.TOT	UG/L		35	1832.28	1755069	1324.79	.723027	223.930	6950.00	400.000	80/07/17	81/10/06
IRON	FE.DISS	UG/L		15	433.333	109752	331.289	.764514	85.5384	1240.00	100.0000	81/04/25	81/07/29
LEAD	PB.DISS	UG/L		14	101.428	10744.0	103.653	1.02193	27.7025	440.000	10.00000	81/04/25	81/07/29
			K	1	10.00000					10.00000	10.00000	81/07/05	81/07/05
			TOT	15	95.3331	10533.8	102.634	1.07659	26.5001	440.000	10.00000	81/04/25	81/07/29
LEAD	PB.TOT	UG/L		34	204.851	15779.8	125.618	.613215	21.5432	520.000	40.0000	80/07/17	81/10/06
			K	1	10.00000					10.00000	10.00000	80/09/02	80/09/02
			TOT	35	199.284	16400.5	128.064	.642623	21.6468	520.000	10.00000	80/07/17	81/10/06
MANGNESE	MN	UG/L		35	104.171	8904.31	94.3626	.905842	15.9502	480.000	20.0000	80/07/17	81/10/06
MANGNESE	MN.DISS	UG/L		14	61.4284	2090.13	45.7179	.744247	12.2186	200.000	20.0000	81/[illegible]/25	81/07/29
			K	1	10.00000					10.00000	10.00000	81/07/21	81/07/21
			TOT	15	57.9998	2117.16	46.0126	.793322	11.8804	200.000	10.00000	81/04/25	81/07/29
NICKEL	NI.TOTAL	UG/L		5	75.9999	530.012	23.0220	.302921	10.2957	100.0000	50.0000	80/07/29	81/07/29
			K	3	73.3333	2133.33	46.1880	.629837	26.6667	100.0000	20.0000	80/08/15	81/07/29
			TOT	8	74.9999	914.293	30.2373	.403164	10.6905	100.0000	20.0000	80/07/29	81/07/29
ZINC	ZN.DISS	UG/L		15	501.333	278527	527.756	1.05271	136.266	2340.00	210.000	81/04/25	81/07/29
ZINC	ZN.TOT	UG/L		35	552.854	188529	434.200	.785379	73.3931	2080.00	120.000	80/07/17	81/10/06
TOT COLI	MPN CONF	TUBECODE		19	511.631	11734.3	108.325	.211724	24.8514	638.000	230.000	80/08/15	81/10/06
			L	1	638.000					638.000	638.000	81/06/06	81/06/06
			TOT	20	517.950	11914.9	109.156	.210745	24.4079	638.000	230.000	80/08/15	81/10/06
FEC COLI	MPN	TUBECODE		19	329.579	20592.6	143.501	.435408	32.9214	638.000	148.000	81/04/29	81/10/06
			K	1	147.000					147.000	147.000	80/08/15	80/08/15
			TOT	20	320.450	21175.5	145.518	.454106	32.5388	638.000	147.000	80/08/15	81/10/06
FEC STRP	MPN-KFBR	TUBE CD		16	346.875	16649.2	129.032	.371983	32.2579	738.000	160.000	80/08/15	81/10/06
FEC STRP	MPN-KFBR	TUBE CD	K	4	248.000	.000000	.000000		.000000	248.000	248.000	81/05/29	81/06/20
			TOT	20	327.100	14790.8	121.617	.371805	27.1945	738.000	160.000	80/08/15	81/10/06
TOT FLOW	COMPOSIT	1000GALS		34	6.47793	23.9429	4.89315	.755357	.839169	22.1000	.490000	80/07/17	81/10/06
PRECIPIT	ATION	IN/STORM		34	.445000	.075450	.274682	.617263	.047108	1.20000	.020000	80/07/17	81/10/06

TABLE 11

STORMWATER RUNOFF DISCRETE SAMPLING DATA

2-PTE/ONPETTEBK 2-PTE
43 08 06.0 070 55 33.0 4
ONSTREAM/PETTEE BK/SOURCE MONITOR/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590867-2954310

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
TURB	TRBIDMTR	HACH FTU	8	72.8750	3326.12	57.6726	.791390	20.3903	170.000	18.0000
CONDUCTVY	AT 25C	MICROMHO	16	833.250	.5999E+07	2449.42	2.93960	612.354	10000.00	35.0000
BOD	5 DAY	MG/L	16	2.33125	.792969	.890488	.381979	.222622	4.00000	1.10000
COD	HI LEVEL	MG/L	15	29.8627	136.416	11.6797	.391114	3.01569	56.0000	16.0000
LAB	PH	SU	16	7.19375	.0779459	.279188	.0388098	.0697969	7.70000	6.70000
T ALK	CACO3	MG/L	8	48.4749	75.7611	8.70409	.179558	3.07736	57.9000	34.0000
RESIDUE	TOTAL	MG/L	16	664.187	.3616E+07	1901.82	2.86337	475.454	7790.00	13.0000
RESIDUE	TOT VOL	MG/L	6	62.3333	671.070	25.9050	.415589	10.5757	111.000	37.0000
RESIDUE	TOT NFLT	MG/L	16	29.1875	2307.90	48.0406	1.64593	12.0101	193.000	1.00000
RESIDUE	VOL NFLT	MG/L	6	5.00000	14.0000	3.74166	.748331	1.52752	10.0000	1.00000
NH3+NH4-	N TOTAL	MG/L	16	.172500	.0149401	.122230	.708579	.0305574	.480000	.100000
TOT KJEL	N	MG/L	13	.817692	.0969192	.311319	.380729	.0863442	1.40000	.390000
NO2&NO3	N-TOTAL	MG/L	16	.506875	.0447696	.211588	.417437	.0528971	.900000	.220000
ORTHOPO4	PO4	MG/L	16	.0369375	.0008886	.0298093	.807021	.0074523	.0839999	.0010000
PHOS-TOT		MG/L P	14	.222214	.143929	.379380	1.70727	.101394	1.20000	.0130000
MGNSIUM	MG.TOT	MG/L	15	6.05333	148.569	12.1889	2.01358	3.14715	50.0000	1.55000
SODIUM	NA.TOT	MG/L	3	978.666	.2768E+07	1663.92	1.70019	960.666	2900.00	18.0000
CHLORIDE	TOTAL	MG/L	16	39.7500	727.666	26.9753	.678624	6.74382	100.000	10.0000
CADMIUM	CD.TOT	UG/L	16	4.99999	.0000326	.0057054	.0011411	.0014264	5.00000	5.00000
CHROMIUM	CR.TOT	UG/L	16	13.1250	49.5834	7.04155	.536499	1.76039	30.0000	10.00000
COPPER	CU.TOT	UG/L	16	99.9998	.0041667	.0645497	.0006455	.0161374	100.0000	100.0000
IRON	FE.TOT	UG/L	16	1247.50	915034	956.574	.766794	239.143	3700.00	100.0000
LEAD	PB.TOT	UG/L	16	45.3123	6721.52	81.9849	1.80933	20.4962	330.000	10.00000
MANGNESE	MN	UG/L	16	176.250	16945.0	130.173	.738571	32.5432	600.000	20.0000
NICKEL	NI.TOTAL	UG/L	8	.100000	.0000000	.0000000	.0000000	.0000000	.100000	.100000
ZINC	ZN.TOT	UG/L	16	48.7499	2451.67	49.5143	1.01568	12.3786	170.000	10.00000
TOT COLI	MPN CONF	TUBECODE	11	359.182	15911.4	126.140	.351188	38.0328	515.000	33.0000
FEC COLI	MPN	TUBECODE	12	256.750	15150.2	123.086	.479401	35.5319	459.000	.0000000
FEC STRP	MPN-KFBR	TUBE CD	13	338.000	12785.8	113.074	.334540	31.3612	588.000	230.000
STREAM	FLOW.	INST-CFS	16	3.67375	10.5679	3.25083	.884881	.812707	11.9000	.400000

STORMWATER RUNOFF DISCRETE SAMPLING DATA

3-PTE/UPPETTEBK 3-PTE
43 08 22.0 070 55 57.0 4
UPSTREAM/PETTEE BK/BACKGROUND/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590868-2954311

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
CONDUCTVY	AT 25C	MICROMHO	7	274.857	25405.9	159.392	.579910	60.2447	633.000	180.000
BOD	5 DAY	MG/L	7	2.77143	3.11573	1.76514	.636908	.667162	6.00000	1.30000
COD	HI LEVEL	MG/L	7	34.1428	475.969	21.8167	.638984	8.24595	75.6000	2.00000
LAB	PH	SU	7	7.14285	.112956	.336089	.0470525	.127030	7.70000	6.70000
T ALK	CACO3	MG/L	7	42.7428	91.5918	9.57036	.223905	3.61726	55.4000	25.0000
RESIDUE	TOTAL	MG/L	6	291.666	54753.6	233.995	.802258	95.5280	731.000	125.000
RESIDUE	TOT NFLT	MG/L	6	16.0000	252.400	15.8871	.992944	6.48598	45.0000	2.00000
NH3+NH4-	N TOTAL	MG/L	7	.104286	.0001286	.0113387	.108729	.0042856	.130000	.100000
TOT KJEL	N	MG/L	6	.693333	.0492668	.221961	.320137	.0906153	1.09000	.500000
NO2&NO3	N-TOTAL	MG/L	7	.439999	.0321337	.179259	.407407	.0677534	.710000	.210000
ORTHOPO4	PO4	MG/L	7	.0055714	.0000156	.0039521	.709348	.0014937	.0100000	.0010000
PHOS-TOT		MG/L P	7	.0505714	.0005486	.0234226	.463160	.0088529	.0909999	.0200000
MGNSIUM	MG.TOT	MG/L	6	3.45000	.455011	.674545	.195520	.275382	4.70000	2.80000
SODIUM	NA.TOT	MG/L	4	62.2500	8433.58	91.8345	1.47525	45.9173	200.000	16.0000
CHLORIDE	TOTAL	MG/L	6	55.8333	1628.97	40.3605	.722875	16.4771	115.000	28.0000
CADMIUM	CD.TOT	UG/L	6	4.24999	3.37504	1.83713	.432266	.750004	5.00000	.500000
CHROMIUM	CR.TOT	UG[illegible]	6	9.99999	.0001953	.0139754	.0013975	.0057054	10.00000	10.00000
COPPER	CU.TOT	UG/L	6	99.9998	.0406250	.201556	.0020156	.0822850	100.0000	100.0000
IRON	FE.TOT	UG/L	7	1114.28	204766	533.634	.478903	201.695	2100.00	500.000
LEAD	PB.TOT	UG/L	7	21.4285	914.284	30.2371	1.41107	11.4286	90.0000	10.00000
MANGNESE	MN	UG/L	7	201.428	12814.3	113.200	.561987	42.7857	410.000	90.0000
NICKEL	NI.TOTAL	UG/L	6	.100000	.0000000	.0000000	.0000000	.0000000	.100000	.100000
ZINC	ZN.TOT	UG/L	7	61.4285	8547.58	92.4531	1.50505	34.9440	260.000	10.00000
TOT COLI	MPN CONF	TUBECODE	6	334.000	926.400	30.4368	.0911281	12.4258	378.000	302.000
FEC COLI	MPN	TUBECODE	5	197.200	2981.22	54.6005	.276879	24.4181	260.000	118.000
FEC STRP	MPN-KFBR	TUBE CD	7	281.143	2370.17	48.6844	.173166	18.4010	360.000	219.000
STREAM	FLOW.	INST-CFS	7	1.15143	.299049	.546854	.474935	.206691	2.22000	.400000

NOTE: All bacteriological data are expressed as Log$_{10}$ (MPN/100 ml sample) x 100

TABLE 12

STORMWATER RUNOFF DISCRETE SAMPLING DATA

7-OYS/UPOYSTER 7-OYS
43 07 57.0 070 56 27.0 4
UPSTREAM/OYSTER R/BACKGROUND/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590873-2954316

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
CONDUCTVY	AT 25C	MICROMHO	15	170.167	1970.50	44.3904	.260864	11.4615	237.000	88.0000
BOD	5 DAY	MG/L	15	9.58666	717.322	26.7829	2.79376	6.91531	106.000	.600000
COD	HI LEVEL	MG/L	13	26.5000	232.083	15.2343	.574879	4.22523	54.5000	4.00000
LAB	PH	SU	15	7.18666	.164115	.405111	.0563699	.104599	8.30000	6.60000
T ALK	CACO3	MG/L	15	25.3999	72.9567	8.54147	.336279	2.20540	35.0000	6.40000
RESIDUE	TOTAL	MG/L	13	122.692	1396.07	37.3640	.304534	10.3629	227.000	67.0000
RESIDUE	TOT VOL	MG/L	1	71.0000					71.0000	71.0000
RESIDUE	TOT NFLT	MG/L	13	14.6923	963.397	31.0386	2.11258	8.60857	117.000	1.00000
RESIDUE	VOL NFLT	MG/L	1	1.00000					1.00000	1.00000
NH3+NH4-	N TOTAL	MG/L	15	.0999997	.4257E-07	.0002063	.0020634	.0000533	.100000	.100000
TOT KJEL	N	MG/L	7	.581428	.0570478	.238847	.410793	.0902756	1.00000	.360000
NO2&NO3	N-TOTAL	MG/L	15	.314666	.0173982	.131902	.419182	.0340570	.520000	.0500000
ORTHOPO4	PO4	MG/L	15	.0053333	.0000478	.0069144	1.29646	.0017853	.0290000	.0010000
PHOS-TOT		MG/L P	15	.0436666	.0010225	.0319769	.732297	.0082564	.146000	.0140000
MGNSIUM	MG,DISS	MG/L	1	3.05000					3.05000	3.05000
MGNSIUM	MG,TOT	MG/L	14	3.01785	1.18986	1.09081	.361451	.291530	5.00000	1.00000
SODIUM	NA,TOT	MG/L	4	14.2500	14.2500	3.77492	.264906	1.88746	19.0000	10.0000
SODIUM	NA,DISS	MG/L	1	14.0000					14.0000	14.0000
PTSSIUM	K,DISS	MG/L	1	1.50000					1.50000	1.50000
PTSSIUM	K,TOT	MG/L	1	1.70000					1.70000	1.70000
CHLORIDE	TOTAL	MG/L	14	28.5714	40.1106	6.33329	.221665	1.69264	38.0000	15.0000
CADMIUM	CD,DISS	UG/L	1	5.00000					5.00000	5.00000
CADMIUM	CD,TOT	UG/L	14	5.07142	.0714580	.267316	.0527104	.0714432	6.00000	5.00000
CHROMIUM	CR,DISS	UG/L	1	10.00000					10.00000	10.00000
CHROMIUM	CR,TOT	UG/L	14	11.4286	13.1869	3.63138	.317746	.970526	20.0000	10.00000
COPPER	CU,DISS	UG/L	1	100.0000					100.0000	100.0000
COPPER	CU,TOT	UG/L	14	107.143	714.303	26.7264	.249447	7.14294	200.000	100.0000
IRON	FE,TOT	UG/L	15	757.331	183024	427.813	.564896	110.461	1600.00	160.000
IRON	FE,DISS	UG/L	1	1100.00					1100.00	1100.00
LEAD	PB,DISS	UG/L	1	10.00000					10.00000	10.00000
LEAD	PB,TOT	UG/L	15	11.0000	15.0001	3.87299	.352091	1.00000	25.0000	10.00000
MANGNESE	MN	UG/L	14	99.2855	2176.37	46.6516	.469874	12.4682	190.000	40.0000
MANGNESE	MN,DISS	UG/L	1	150.000					150.000	150.000
NICKEL	NI,TOTAL	UG/L	11	.100909	.0018091	.0425338	.421506	.0128244	.200000	.0100000
ZINC	ZN,DISS	UG/L	1	20.0000					20.0000	20.0000
ZINC	ZN,TOT	UG/L	15	95.9999	51425.5	226.772	2.36221	58.5523	900.000	10.00000
TOT COLI	MPN CONF	TUBECODE	13	263.308	3425.78	58.5301	.222288	16.2333	356.000	160.000
FEC COLI	MPN	TUBECODE	15	156.200	5125.89	71.5953	.458357	18.4858	300.000	70.0000
FEC STRP	MPN-KFBR	TUBE CD	15	190.333	4235.67	65.0820	.341937	16.8041	300.000	70.0000
STREAM	FLOW,	INST-CFS	16	7.60000	70.4800	8.39524	1.10464	2.09881	32.0000	3.00000

NOTE: All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 13

STORMWATER RUNOFF DISCRETE SAMPLING DATA

5-OYS/DNOYSTER 5-OYS
43 07 50.0 070 55 11.0 4
DNSTREAM/OYSTER R/SOURCE MONITOR/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590872-2954315

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
TURB	TRBIDMTR	HACH FTU	10	17.9500	793.484	28.1688	1.56929	8.90777	98.0000	7.00000
CNDUCTVY	AT 25C	MICROMHO	25	192.200	1519.87	38.9855	.202838	7.79709	316.000	114.000
BOD	5 DAY	MG/L	24	2.18333	2.56059	1.60019	.732911	.326636	6.00000	.200000
COD	HI LEVEL	MG/L	23	33.1434	266.556	16.3265	.492603	3.40432	82.3000	7.20000
LAB	PH	SU	25	7.12399	.107717	.328202	.0460700	.0656404	7.60000	6.20000
T ALK	CACO3	MG/L	15	29.0666	122.716	11.0777	.381114	2.86025	53.7000	9.10000
RESIDUE	TOTAL	MG/L	24	124.083	1591.65	39.8955	.321522	8.14363	234.000	11.0000
RESIDUE	TOT VOL	MG/L	11	80.1818	251.769	15.8672	.197890	4.78415	97.0000	57.0000
RESIDUE	TOT NFLT	MG/L	23	5.82609	54.2411	7.36486	1.26412	1.53568	35.0000	1.00000
RESIDUE	VOL NFLT	MG/L	11	2.09091	1.89091	1.37510	.657659	.414610	4.00000	1.00000
NH3+NH4-	N TOTAL	MG/L	15	.101333	.0000267	.0051671	.0509909	.0013341	.120000	.100000
TOT KJEL	N	MG/L	8	.587499	.0752217	.274266	.466836	.0969675	.980000	.100000
NO2&NO3	N-TOTAL	MG/L	15	.205333	.0144840	.120349	.586118	.0310741	.410000	.0500000
ORTHOPO4	PO4	MG/L	15	.0038667	.0000043	.0020656	.534203	.0005333	.0080000	.0010000
PHOS-TOT		MG/L P	15	.0592000	.0014829	.0385082	.650476	.0099428	.164000	.0230000
MGNSIUM	MG,DISS	MG/L	1	3.45000					3.45000	3.45000
MGNSIUM	MG,TOT	MG/L	23	2.86739	.544708	.738043	.257392	.153893	4.10000	.350000
SODIUM	NA,TOT	MG/L	5	19.0000	109.500	10.4642	.550749	4.67974	37.0000	10.0000
SODIUM	NA,DISS	MG/L	1	37.0000					37.0000	37.0000
PTSSIUM	K,DISS	MG/L	1	2.90000					2.90000	2.90000
PTSSIUM	K,TOT	MG/L	1	2.90000					2.90000	2.90000
CHLORIDE	TOTAL	MG/L	24	29.2917	30.9118	5.55984	.189810	1.13490	50.0000	21.0000
CADMIUM	CD,DISS	UG/L	1	5.00000					5.00000	5.00000
CADMIUM	CD,TOT	UG/L	24	4.99999	.0000000	.0000000	.0000000	.0000000	5.00000	5.00000
CHROMIUM	CR,DISS	UG/L	1	10.00000					10.00000	10.00000
CHROMIUM	CR,TOT	UG/L	24	16.2499	85.3276	9.23729	.568452	1.88555	30.0000	10.00000
COPPER	CU,DISS	UG/L	1	100.0000					100.0000	100.0000
COPPER	CU,TOT	UG/L	24	99.9998	.0000000	.0000000	.0000000	.0000000	100.0000	100.0000
IRON	FE,TOT	UG/L	25	887.997	60269.3	245.498	.276463	49.0996	1200.00	200.000
IRON	FE,DISS	UG/L	1	600.000					600.000	600.000
LEAD	PB,DISS	UG/L	1	10.00000					10.00000	10.00000
LEAD	PB,TOT	UG/L	25	10.8000	5.58385	2.36302	.218798	.472603	20.0000	10.00000
MANGNESE	MN	UG/L	25	113.200	2122.67	46.0725	.407001	9.21449	250.000	40.0000
MANGNESE	MN,DISS	UG/L	1	240.000					240.000	240.000
NICKEL	NI,TOTAL	UG/L	13	.0999998	.2980E-07	.0001726	.0017263	.0000479	.100000	.100000
ZINC	ZN,DISS	UG/L	1	40.0000					40.0000	40.0000
ZINC	ZN,TOT	UG/L	25	33.9999	1225.01	35.0001	1.02942	7.00002	170.000	10.00000
TOT COLI	MPN CONF	TURECODE	25	349.920	6104.16	78.1291	.223277	15.6258	563.000	170.000
FEC COLI	MPN	TUBECODE	24	253.417	7947.26	89.1474	.351782	18.1971	397.000	70.0000
FEC STRP	MPN-KFBR	TUBE CD	25	263.120	6868.96	82.8792	.314986	16.5758	463.000	100.000
STREAM	FLOW,	INST-CFS	26						363.000	3.00000

NOTE: All bacteriological data are expressed in Log_{10} (MPN/100 ml sample) x 100

TABLE 14

STORMWATER RUNOFF DISCRETE SAMPLING DATA

1-PKG/PARKINLOT 1-PKG
43 07 59.0 070 55 39.0 4
SHOP-SAVE/COMMERCIAL PARKING LOT/DURHAM NH
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY 810509
0000 FEET DEPTH CLASS 04 CSN-RSP 0590866-2954309

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	COEF VAR	STAND ER	MAXIMUM	MINIMUM
CONDUCTVY	AT 25C	MICROMHO	52	62.9577	3276.10	57.2372	.909139	7.93738	268.000	16.0000
BOD	5 DAY	MG/L	53	21.6151	299.891	17.3174	.801171	2.37872	84.0000	4.00000
COD	HI LEVEL	MG/L	29	107.221	6823.34	82.6035	.770407	15.3391	293.000	.0000000
LAB	PH	SU	53	4.55660	.226699	.476129	.104492	.0654013	6.10000	3.50000
RESIDUE	TOTAL	MG/L	51	96.7451	7362.84	85.8070	.886939	12.0154	336.000	21.0000
RESIDUE	TOT VOL	MG/L	2	106.000	6962.00	83.4386	.787157	59.0000	165.000	47.0000
RESIDUE	TOT NFLT	MG/L	50	32.8600	1567.84	39.5959	1.20499	5.59971	217.000	1.00000
RESIDUE	VOL NFLT	MG/L	2	1.00000	.0000000	.0000000	.0000000	.0000000	1.00000	1.00000
NH3+NH4-	N TOTAL	MG/L	53	.246792	.0807948	.284244	1.15176	.0390440	1.70000	.100000
TOT KJEL	N	MG/L	3	2.33000	1.02270	1.01128	.434028	.583866	3.40000	1.39000
NO2&NO3	N-TOTAL	MG/L	51	.529018	.256985	.506937	.958261	.0709853	2.00000	.0799999
ORTHOPO4	PO4	MG/L	28	.0671069	.0067446	.0821256	1.22380	.0155203	.310000	.0000000
PHOS-TOT		MG/L P	49	.121163	.0111647	.105663	.872076	.0150947	.387000	.0030000
MGNSIUM	MG.TOT	MG/L	50	.833455	.410994	.641088	.769193	.0906634	3.10000	.0430000
SODIUM	NA.TOT	MG/L	47	2.74468	6.12210	2.47429	.901486	.360912	9.00000	.400000
CHLORIDE	TOTAL	MG/L	26	6.26923	54.9246	7.41111	1.18214	1.45344	37.0000	2.00000
CADMIUM	CD.TOT	UG/L	50	6.47993	5.11260	2.26111	.348940	.319769	10.00000	5.00000
CHROMIUM	CR.TOT	UG/L	50	17.3998	72.6968	8.52624	.490019	1.20579	40.0000	10.00000
COPPER	CU.TOT	UG/L	50	109.999	918.597	30.3084	.275534	4.28625	200.000	100.0000
IRON	FE.TOT	UG/L	50	1389.79	.1763E+07	1327.83	.955418	187.784	8000.00	100.0000
LEAD	PB.TOT	UG/L	50	219.498	28091.1	167.604	.763579	23.7028	740.000	30.0000
MANGNESE	MN	UG/L	50	95.1993	5931.67	77.0173	.809012	10.8919	350.000	30.0000
NICKEL	NI.TOTAL	UG/L	48	96.2493	330.400	18.1769	.188852	2.[illegible]351	100.0000	10.00000
ZINC	ZN.TOT	UG/L	49	564.282	456613	675.731	1.19750	96.5310	2900.00	40.0000
TOT COLI	MPN CONF	TUBECODE	18	402.222	3585.76	59.8813	.148876	14.1141	497.000	295.000
FEC COLI	MPN	TUBECODE	18	280.944	3843.35	61.9948	.220666	14.6123	418.000	148.000
FEC STRP	MPN-KFBR	TUBE CD	18	315.666	4768.41	69.0537	.218755	16.2761	463.000	236.000
STREAM	FLOW,	INST-CFS	64	1722.98	.1444E+08	3800.17	2.20557	475.021	9999.00	.0200000

NOTE. All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 15

1981 PRECIPITATION QUALITY*

SUMMARY

Parameter	# of Samples	Concentration		St. Dev.
		Range	Mean	
BOD	16	0.900 - 8.000	3.175	2.053
COD	16	4.000 - 35.500	13.769	8.761
Total Solids	11	2.000 - 96.000	23.455	27.905
Susp. Solids	11	1.000 - 13.000	2.909	3.727
NH_3	16	0.100 - 0.900	0.358	0.220
TKN	14	0.180 - 0.710	0.421	0.195
$NO_2 + NO_3$	16	0.090 - 2.100	0.561	0.507
PO_4	15	0.001 - 0.017	0.005	0.006
P	13	0.001 - 0.099	0.030	0.035
Mg	15	0.010 - 0.200	0.087	0.077
Na	15	0.422 - 2.000	1.133	0.352
K	15	0.100 - 0.500	0.153	0.106
ALK	1	4.500 - 4.500	4.500	M
CL	11	2.000 - 5.000	2.545	1.036
pH (Std.)	16	3.700 - 4.500	4.000	0.213
Spec. Cond.	16	16.700 - 104.000	53.075	30.071
Cd	11	0.005 - 0.005	0.005	0.000
Cr	11	0.010 - 0.030	0.026	0.008
Cu	11	0.100 - 0.100	0.100	0.00
Fe	11	0.100 - 0.100	0.100	0.000
Pb	11	0.010 - 0.010	0.010	0.000
Mn	11	0.010 - 0.010	0.010	0.000
Zn	11	0.130 - 0.400	0.165	0.086
Total	10	30 - 23,000	550	14.56
Fecal	10	30 - 15,000	427	11.55
Fecal Strep	10	30 - 23,000	231	10.74

*Data Collected April - October 1981

TABLE 16

1982 PRECIPITATION QUALITY

Storm Date	pH Std. Units	Specific Conductance
12 June 1982	4.50	10.0
1 June 1982	3.30	32.0
21 June 1982	3.45	28.0
22 June 1982	4.18	15.0
28 June 1982	3.60	-
29 June 1982	3.35	45.0
20 July 1982	3.50	20.0
29 July 1982	3.80	-
25 August 1982	3.20	-
14 Oct. 1982	3.40	65.0
Mean	3.61	30.7

TABLE 17

OYSTER RIVER ESTUARY
WATER QUALITY DATA SUMMARY

1980

TABLE: 1980 SAMPLING DATA PISCATAQUA RIVER BASIN BRANCH: OYSTER RIVER

DATE	TIME	CURRENT STAGE	DEPTH (feet)	TEMP (°C)	WEATHER	SALINITY	SPEC. COND.	COLIFORM TOTAL (MPN)	COLIFORM TOTAL (MF-Cts)	COLIFORM FECAL (MF-Cts)
STATION: 47a		LOCATION: 0.6 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°07.0'		LONG. 70°55.1'
27 MAR	1105	0:43 E	5	4	OVC/CALM	2	2,250		20	
24 JUN	1118	0:10 E	5	20	CLR/SW-10	15.5	23,000		500	
6 AUG	1207	1:45 E	5	27	CLR/CALM	17.5	30,000		>20,000	
STATION: 47		LOCATION: 0.34 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°08.0'		LONG. 70°54.7'
27 MAR	1113	0:51 E	5	3	OVC/CALM	4.5	3,000		30	
24 JUN	1125	0:17 E	4	20	CLR/SW-10	16.5	24,000		<10	
6 AUG	1213	1:51 E	4	26	CLR/CALM	17	28,000		>2,000	
STATION: 48a		LOCATION: 0.72 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°08.1'		LONG. 70°54.2'
27 MAR	1118	0:56 E	4	2.5	OVC/CALM	10	9,000		<10	
24 JUN	1129	0:21 E	4	20	CLR/SW-10	18	26,000		<10	
6 AUG	1218	1:56 E	3	26	CLR/CALM	18	31,000		>2,000	
STATION: 48		LOCATION: 1.3 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°07.9'		LONG. 70°53.7'
27 MAR	1127	1:05 E	7	4	OVC/CALM	11	11,500		<10	
24 JUN	1134	0:26 E	7	20	CLR/SW-10	19	27,500		<10	
6 AUG	1225	2:03 E	5	25	CLR/CALM	20	32,000		>2,000	
STATION: 01		LOCATION: 1.7 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°07.9'		LONG. 70°53.2'
27 MAR	1132	1:10 E	14	3	OVC/CALM	13	13,000		<10	
24 JUN	1140	0:32 E	9	18	CLR/SW-10	19	28,000		<10	
STATION: 49		LOCATION: 2.0 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°07.8'		LONG. 70°53.0'
27 MAR	1135	1:13 E	15	3.5	OVC/CALM	13	13,000		10	
24 JUN	1143	0:35 E	16	16	CLR/SW-10	20	27,000		<10	
6 AUG	1230	2:08 E	15	25	CLR/CALM	21	34,000		>2,000	
STATION 49a		LOCATION: 2.2 MILES BELOW TIDAL DAM (500ys)						LAT. 43°07.5'		LONG. 70°52.8'
27 MAR	1137	1:15 E	12	4	OVC/CALM	12	12,500		<10	
24 JUN	1145	0:37 E	13	18	CLR/SW-10	20	27,500		<10	
6 AUG	1233	2:11 E	9	25	CLR/CALM	20.5	33,000		>2,000	
STATION: 50		LOCATION: 2.8 MILES BELOW TIDAL DAM (5-Oys)						LAT. 43°07.7'		LONG. 70°52.1
27 MAR	1143	1:21 E	6	3	OVC/CALM	13	13,000		<10	
24 JUN	1150	0:42 E	5	18	CLR/SW-10	19.5	27,000		<10	
6 AUG	1236	2:14 E	5	25	CLR/CALM	20	33,500		890	

I.5 DATA ANALYSIS AND DISCUSSION

Rainfall/Runoff Relationships

Increases in impervious land cover resulting from urbanization typically produce quantitative increases in surface runoff generated by storm events. This phenomenon is well documented in the literature and is obvious in the results of this study.

Several factors influence the quality of rainfall realized as runoff, including surface depression losses, soil infiltration, vegetal interception, and soil moisture content. For this reason, the rainfall/runoff relationship is not static and, therefore, is difficult to accurately predict.

The dimensionless ratio of runoff to rainfall volume for storm events within a catchment area is defined by hydrologists as the runoff coefficient. Table 18 presents runoff coefficients for storm events measured at each of the five study catchments. As would be expected, the annual mean values reflect the influence of urbanization on the quality of rainfall experienced as surface runoff, with the highest coefficients occurring in the heavily urbanized catchments and lowest in the least urbanized catchments. Review of these data does not suggest any significant seasonal variations in runoff coefficients computed within each catchment.

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TABLE 18

SEASONAL AND ANNUAL
STORMWATER RUNOFF COEFFICIENTS

			Runoff Coefficients				
Season	Storm Date	Precip. Inches	3-Pte	2-Pte	7-Oys	5-Oys	1-Pkg
Spring	23 Apr.	0.77	-	-	-	-	.64
	29 Apr.	0.16	.05	.08	-	-	.15
	29 Apr.	0.27	-	-	-	-	.40
	15 May	0.90	-	.17	-	-	-
	29 May	0.22	.04	.09	-	-	.54
	31 May	0.39	-	-	-	-	.75
	04 Jun	0.20	-	-	-	-	.50
	06 Jun	0.08	-	-	-	-	.78
	09 Jun	0.68	-	-	.05	.21	.95
	20 Jun	0.80	-	-	.08	.13	.78
Spring	Mean	.04	.05	.11	.06	.17	.61
Flow Wt. Season	Mean	-	.04	.14	.07	.13	.75
Summer	22 Jun	0.06	-	-	-	-	.74
	25 Jun	0.07	-	-	.02	.06	.77
	05 Jul	0.70	-	-	.05	.16	.72
	06 Jul	1.20	-	-	-	-	.88
	09 Jul	0.14	-	-	-	-	.82
	13 Jul	0.50	-	-	.01	.02	.53
	17 Jul	0.38	-	-	-	.49	

TABLE 18 (Continued)

SEASONAL AND ANNUAL STORMWATER RUNOFF COEFFICIENTS

	Storm	Precip.		Runoff Coefficients			
Season	Date	Inches	3-Pte	2-Pte	7-Oys	5-Oys	1-Pkg
Summer	18 Jul	0.50	-	-	.03	.03	-
	20 Jul	0.85	-	-	.06	.06	.51
	29 Jul	0.76	.11	.10	.08	.16	.47
	29 Jul	0.89	-	-	-	-	.84
	05 Aug	0.20	-	.07	-	-	.81
	05 Aug	0.02					1.88
	07 Aug	0.60					.65
	15 Aug	0.20					.75
	16 Aug	0.41	-	.08	.05	-	.57
	19 Aug	0.34	-	-	-	-	.94
	24 Aug	0.50	.01	-	-	-	.29
	02 Sep	0.28	-	-	-	-	.92
	09 Sep	0.50	.03	.06	-	-	.52
	14 Sep	0.18	-	-	-	-	1.08
	16 Sep	0.40	.03	.06	-	.09	-
	18 Sep	0.55	.03	.03	-	-	-
	19 Sep	0.40	.05	.06	-	.20	-
	22 Sep	2.10	-	-	.03	.06	.79
Summer	Mean	0.51	.04	.07	.07	.09	.76
Flow Wt.	Mean	-	.06	.08	.06	.10	.74

TABLE 18 (Continued)

SEASONAL AND ANNUAL STORMWATER RUNOFF COEFFICIENTS

Season	Storm Date	Precip. Inches	Runoff Coefficients				
			3-Pte	2-Pte	7-Oys	5-Oys	1-Pkg
Autumn	24 Sep	0.18	-	-	-	-	.74
	26 Sep	1.03	.03	.05	-	-	-
	01 Oct	0.36	.05	.05	.01	.08	.27
	03 Oct	1.09	.04	-	-	-	-
	06 Oct	0.25	.03	.05	.05	.09	.54
	18 Oct	0.42	.03	.04	.02	.09	.69
	25 Oct	2.67	.05	.08	-	-	-
	26 Oct	0.30	.06	.08	-	-	-
	06 Nov	0.31	.06	.07	.07	-	-
	23 Nov	1.00	.08	.08	.24	.132	-
	01 Dec	1.53	-	-	.24	.30	-
Autumn Mean		.83	.05	.06	.10	.14	.56
Flow Wt. Mean		-	.06	.08	.21	.20	.61
Annual Mean			.05	.07	.08	.12	.70
Flow Wt. Mean			.06	.09	.16	.15	.73

Stormwater Quality Influencing Factors

In an effort to define the important factors influencing stormwater runoff quality in each of the study catchments, multiple linear regression analyses were performed utilizing storm intensity, total precipitation volume, and antecedent dry period as the independent variables. Results of these analyses are presented in tables 19 through 21.

Results for the parking lot site show these variables are significant ($\alpha = .05$) in explaining some degree of variability in 17 of the 36 parameters monitored, accounting for only about 14% of the total observed variability in runoff quality.

The results obtained highlight an interesting trend. With the exception of bacteria concentrations which exhibited extreme variability, the three independent variables are quite consistent in terms of the direction of influence. Decreased contaminant concentrations result from increasing precipitation volumes suggesting dilution of "first flush" contaminant washoff. Also, increased contaminant concentrations result from pavement scourings associated with increasing storm intensity, and also from increasing dry periods between storm events indicating gradual build-up of pollutants over time on the pavement surface.

As with the parking lot site, results for Pettee Brook suggest that precipitation volume is the most influential variable addressed, however, the variables are positively correlatd in Pettee Brook which is opposite to the effect observed at 1-Pkg. This result is to be expected in less urbanized catchments where "first flush" phenomena do not predominate.

TABLE 19
1-PKG
Multiple Regression Analysis
Stormwater Runoff Quality
Vs.
Storm Intensity, Precipitation Volume, Antecedent Dry Period
R^2 Change

	Storm Intensity	Precip. Volume	Dry Period	Total
Total Coliform	-	-	(+) .20[b]	.20
Fecal Coliform	(-) .11	(+) .16	-	.27
Fecal Strep	-	-	-	-
BOD	-	-	-	-
COD	-	(-) .34	-	.34
TKN	-	(-) .30	(+) .25	.55
NH_3	-	-	(+) .07	.07
NO_2+NO_3	-	-	-	-
PO_4	-	-	-	-
P	-	(-) .12	-	.12
Cd	-	-	-	-
Cr	-	-	-	-
Cu	-	-	-	-
Fe	-	(-) .20	-	.20
Pb	-	(-) .19	-	.19
Mg	-	-	-	-
Mn	-	(-) .18	-	.18
K	(+) .17	-	-	.17
Na	(+) .17	(-) .15	-	.32
Zn	-	-	-	-
Alkalinity	-	-	-	-
Cl	-	-	-	-
Spec. Cond.	-	-	(+) .11	.11
Turbidity	(+) .39	(-) .47	-	.86
Total Residue	-	(-) .34	-	.34
SUS Residue	-	(-) .14	-	.14
Tot. Vol. Residue	-	(-) .28	(+) .17	.45
SUS Vol. Residue	-	-	-	-
Cd, diss	-	-	-	-
Cr, diss	-	-	-	-
Cu, diss	-	-	-	-
Fe, diss	-	(-) .45	-	.45
Pb, diss	-	-	-	-
Mg, diss	-	-	-	-
Mn, diss	-	-	-	-
Zn, diss	-	-	-	-

a - Nie, N. H., and C. H. Hull. SPSS Update 7-9. McGraw Hill 1981 New Regression Procedure; default criteria F = .05 for entry of independent variable into regression model.

b - (+) or (-) indicates direction of influence; from correlation analysis.

TABLE 20
PETTEE BROOK
Multiple Regression Analysis[a]
Stormwater Runoff Quality
Vs.
Storm Intensity, Precipitation Volume, Antecedent Dry Period
R^2 Change

	Upstream (3-Pte)				Downstream (2-Pte)			
	Storm Intensity	Precip. Volume	Dry Period	Total	Storm Intensity	Precip. Volume	Dry Period	Total
Total Coliform	-	-	-	-	-	-	-	-
Fecal Coliform	-	-	-	-	-	-	-	-
Fecal Strep	-	-	-	-	-	-	-	-
BOD	-	-	-	-	-	-	-	-
COD	-	-	-	-	-	-	-	-
TKN	(+).06[b]	(+).93	-	.99	-	-	-	-
NH_3	-	-	-	-	-	-	-	-
NO_2+NO_3	-	-	-	-	-	(-).38	-	.38
PO_4	-	-	-	-	-	-	-	-
P	-	(+).56	-	.56	(+).41	(+).37	-	[illegible]
Cd	-	-	-	-	-	-	-	
Cr	-	-	-	-	-	-	-	
Cu	-	-	-	-	-	-	-	.
Fe	-	(+).76	-	.76	-	(+).41	-	.41
Pb	-	(+).20	-	.20	-	-	-	-
Mg	-	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	-
K	-	-	-	-	-	(+).50	-	.50
Na	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-
Alkalinity	-	(-).67	-	.67	-	-	-	-
Cl	(-).31	-	-	.31	-	-	-	-
Spec. Cond.	(-).40	-	-	.40	-	-	-	-
Turbidity	-	-	-	-	-	-	-	-
Total Residue	-	(+).71	-	.71	-	-	-	-
SUS Residue	-	(+).71	-	.71	-	(+).34	-	.34
Tot. Vol. Residue	-	-	-	-	-	-	-	-
SUS Vol. Residue	-	-	-	-	(+).41	(+).53	-	.94

a. Nie, N. H., and C. H. Hull. SPSS Update 7-9. McGraw Hill 1981. New Regression Procedure; default criteria F = .05 for entry of independent variable into regression model.

b. (+) or (-) indicates direction of influence, from correlation coefficient.

TABLE 21
OYSTER RIVER
Multiple Regression Analysis[a]
Stormwater Runoff Quality vs.
Vs.
Storm Intensity, Precipitation Volume, Antecedent Dry Period
R^2 Change

	Upstream (7-Oys)				Downstream (5-Oys			
	Storm Intensity	Precip. Volume	Dry Period	Total	Storm Intensity	Precip. Volume	Dry Period	Total
Total Coliform	-	(+).64	-	.64	-	(+).70	-	.70
Fecal Coliform	-	(+).62	-	.62	-	(+).52	-	.52
Fecal Strep	-	-	-	-	-	-	-	-
BOD	-	-	-	-	-	-	-	-
COD	-	-	-	-	-	-	-	-
TKN	-	-	-	-	-	-	-	-
NH_3	-	-	-	-	-	-	-	-
NO_2+NO_3	-	-	-	-	-	-	-	-
PO_4	-	-	-	-	-	-	-	-
P	-	-	-	-	-	(+).51	-	.51
Cd	-	-	-	-	-	-	-	-
Cr	-	-	-	-	-	-	-	-
Cu	-	-	-	-	-	-	-	-
Fe	-	-	-	-	-	-	-	-
Pb	-	-	-	-	-	-	-	-
Mg	-	-	-	-	-	-	-	-
Mn	-	-	-	-	-	-	-	-
K	-	-	-	-	-	-	-	-
Na	-	-	-	-	-	-	-	-
Zn	-	-	-	-	-	-	-	-
Alkalinity	-	-	-	-	-	-	-	-
Cl	-	-	-	-	-	-	-	-
Spec. Cond.	-	-	-	-	-	-	-	-
Turbidity	-	-	-	-	(+).58	-	(-).15	.73
Total Residue	-	-	-	-	-	-	-	-
SUS Residue	-	-	-	-	(+).33	-	-	.33
Tot. Vol. Residue	-	-	-	-	-	-	-	-
SUS Vol. Residue	-	-	-	-	-	-	-	-
Cd, diss	-	-	-	-	-	-	-	-
Cr, diss	-	-	-	-	-	-	-	-
Cu, diss	-	-	-	-	-	-	-	-
Fe, diss	-	-	-	-	-	-	-	-
Pb, diss	-	-	-	-	-	-	-	-
Mg, diss	-	-	-	-	-	-	-	-
Mn, diss	-	-	-	-	-	-	-	-
Zn, diss	-	-	-	-	-	-	-	-

a. Nie, N. H., and C. H. Hull. SPSS Update 7-9. McGraw Hill 1981
New Regression Procedure; default criteria F = .05 for entry of independent variable into regression model.

b. (+) or (-) indicates direction of influence from correlation analysis.

Overall, the independent variables account for only a limited portion of the observed variability at each of the two Pettee Brook stations. Upstream, variability in 9 of the 28 parameters is at least partially explained, accounting for 19% of the total variability. Downstream, variability in 6 of the 28 parameters is partially explained, accounting for 11% of the total observed variability in runoff quality.

Variability in Oyster River runoff quality is also influenced only to a minor degree by the independent variables in the analysis. Upstream, only total and fecal coliforms are significantly influenced, and at that only by precipitation volume. Overall only 4% of the total variability can be accounted for. Downstream, 8% of the total variability is accounted for in 8 of 36 parameters monitored.

Summary

Overall, the independent variables - storm intensity, precipitation volume and antecedent dry period can account for only a limited degree of the observed variability in runoff quality at each station, ranging from a low of 4% upstream in the Oyster River to a high of 19% upstream in Pettee Brook.

Of the 3 independent variables, precipitation volume emerges as the factor having the greatest influence on observed runoff quality. However, a negative correlation predominates at the 1-Pkg site - opposite the effect precipitation volume has on runoff quality at the other stations. This result tends to support the "first flush" theory that most of the pollutants which accumulate on impervious areas such as the parking lot surface are removed in the initial runoff which would result in greatest concentrations occurring with small precipitation volumes. Added preciptiation would, therefore, tend to dilute constituent concentrations in the "end of pipe" composite samples collected at the 1-Pkg site.

Conversely, Pettee Brook and Oyster River samples were collected in-stream where base flow dilution must be overwhelmed before significant changes in water quality become apparent. This typically requires substantial stormwater runoff inputs which tend to result in scouring velocities in the stream channel as well as surface scour.

Both storm intensity and antecedent dry period tend to produce concentration increases at the 1-Pkg site. These factors are of such minor influence in both the Oyster River and Pettee Brook that no trend can be defined.

Stormwater Runoff Impacts on Receiving Water Quality

Water quality data presented in the preceding tabulated summaries have been used to determine the impact of stormwater runoff on receiving stream quality. Data collected at upstream and downstream locations in the Pettee Brook and Oyster River catchments have been used to bracket the urban catchments chosen for study, enabling identification of urban runoff influences independent of any background residual contamination.

Table 22 summarizes the results of statistical tests intended to verify the significance of contaminant concentration changes between upstream and downstream sampling locations in the Pettee Brook catchment. Dry weather data have been tested to determine if base flow quality is significantly different between the upstream and downstream stations. Significant concentration increases suggest the presence of contaminant input, while concentration decreases would imply the existence of contaminant "sinks". Test results suggest that fecal coliform, TKN, and substances contributing to increased specific conductance are discharged to Pettee Brook, resulting in significantly elevated downstream concentrations, and that manganese concentrations are attenuated between the stations, perhaps via settling or other mechanisms.

Similar comparisons of stormwater quality reveal a net decrease in fecal coliform and COD, and an increase in total volatile solids between the two Pettee Brook stations. Due to the greater degree of urbanization in the 2-Pte (downstream) catchment, significant concentration increases were expected for most constituents. As with the unexpected results of the dry weather data analysis, the absence

TABLE 22

Pettee Brook Catchment
Significant Difference of Mean Concentrations

(Paired t-test, 1-tail prob., $\alpha \leq .05$)

	Dry Weather Upstream vs Downstream 3-Pte vs 2-Pte	Storm Composite Upstream vs Downstream 3-Pte vs 2-Pte	Dry Weather vs Storm Composite Upstream 3-Pte	 Downstream 2-Pte
Total Coliform	-	-	.000	.000
Fecal Coliform	.019	.040*	.000	.000
BOD	-	-	.000	.005
COD	-	.039*	.006	.000
TKN	.002	-	-	.000
NH_3	-	-	-	-
NO_2+NO_3	-	-	.000	.000
PO_4	-	-	-	.044
P	-	-	.005	.000
Cd	-	-	-	.026
Cr	-	-	.000	-
Cu	-	-	-	-
Fe	-	-	.000	.000
Pb	-	-	.004	.003
Mn	.004*	-	.002	.000
Zn	-	-	.000	.000
Spec Cond	.010	-	-	-
Total Solids	-	-	.012	.012
Sus. Solids	-	-	.000	.002
Tot Vol Solids	-	.04	ND	ND
Sus Vol Solids	-	-	ND	ND

*Upstream mean concentration greater than downstream of this trend suggests that concentration increases caused by urban runoff may be masked by background discharges within the reach. As discussed elsewhere, the University swimming pool filter backwash discharges to Pettee Brook may account for these results.

Dry weather data are also valuable in identifying significant differences between storm influenced and base flow quality. Table 22 reflects the impact of stormwater runoff on stream quality at both stations in Pettee Brook. These results substantiate the fact that both rural and urban areas can contribute significant contaminant loads as a result of stormwater runoff.

As with Pettee Brook, stormwater runoff influences are revealed by comparing dry weather data with stormwater runoff stream influenced water quality data. Table 23 presents this information as well as significant differences in Oyster River water quality during dry weather and storm influenced stream conditions. Similar to Pettee Brook, dry weather water quality is relatively stable between the upstream and downstream Oyster River stations, although a significant decrease in both BOD and specific conductivity is indicated. This phenomenon is even more pronounced in the stormwater runoff influenced samples collected at these stations. Decreases in coliform bacteria, phosphorus, solids and specific conductivity are significant. Only nitrate-nitrite concentrations increase significantly between the stations.

This trend of decreasing constituent concentrations may at first seem counter-intuitive since the sampling strategy was designed to bracket the Durham urban area, thereby isolating the influence of

TABLE 23

Oyster River Catchment
Significant Difference of Mean Concentrations
(Paired t-test, 1-tail prob., $\alpha \leq .05$)

	Dry Weather	Storm Composite	Dry Weather vs Storm Composite	
	Upstream vs Downstream	Upstream vs Downstream	Upstream	Downstream
	7-Dys 5-Dys	7-Dys 5-Dys	7-Dys	5-Dys
Total Coliform	-	.000*	-	.000
Fecal Coliform	-	.007*	.000	.000
BOD	.002*	-	.002	.008
COD	-	-	-	-
TKN	-	-	.000	.000
NH_3	-	-	-	-
NO_2+NO_3	-	.027	.038	-
PO_4	-	.001*	.025	.003
P	-	.024*	.005	.000
Cd	-	-	-	-
Cr	-	-	.001	.008
Cu	-	-	-	-
Fe	-	-	.019	.000
Pb	-	-	-	-
Mn	-	-	-	-
Zn	-	-	.002	.024
Spec Cond	.001*	.000*	-	-
Total Solids	-	.022*	-	-
Sus. Solids	-	-	-	.048
Tot Vol Solids	-	-	ND	ND
Sus Vol Solids	-	-	ND	ND

*Upstream mean concentration greater than downstream urban stormwater runoff manifested in elevated constituent concentrations at the downstream station. Settling, aquatic plant uptake, and perhaps other attenuating mechanisms occurring in the impoundment immediately upstream of 5-Oys (Mill Pond) are presumed responsible for the observed concentration decreases. In fact, 1980 late summer dry weather sampling data revealed supressed dissolved oxygen concentrations at 5-Oys, presumably caused by sediment oxygen demand of settled materials.

In an attempt to verify this, an analysis of sediment oxygen demand (SOD) was undertaken at three locations in Mill Pond and at two locations upstream in the Durham water supply reservoir above 7-Oys (Figure 6). In addition to SOD, chemical analyses for several metals and solids were performed by Environmental Protection Agency staff at the Region I laboratory. These results appear in Table 24. The complete report prepared by EPA Region I staff is found in Appendix A.

Study results indicate moderate to high SOD rates in both Mill Pond and in the water supply reservoir. Highest rates were observed at the head of each impounded area where dead vegetation and other organic debris carried by the influent stream accumulate on the bottom, decompose, and exert considerable oxygen demand on the overlying water.

Sediment oxygen demand rates observed at the dam locations (5-Oys and 7-Oys) revealed significantly higher SOD rates at 5-Oys when compared with 7-Oys, indicating increased accumulations of organic debris at this downstream location in the Oyster River. These results support late summer 1980 dry weather water quality data which show depressed dissolved oxygen concentrations at both 5-Oys and

FIGURE 6

OYSTER RIVER SEDIMENT CHEMISTRY
SAMPLING STATIONS

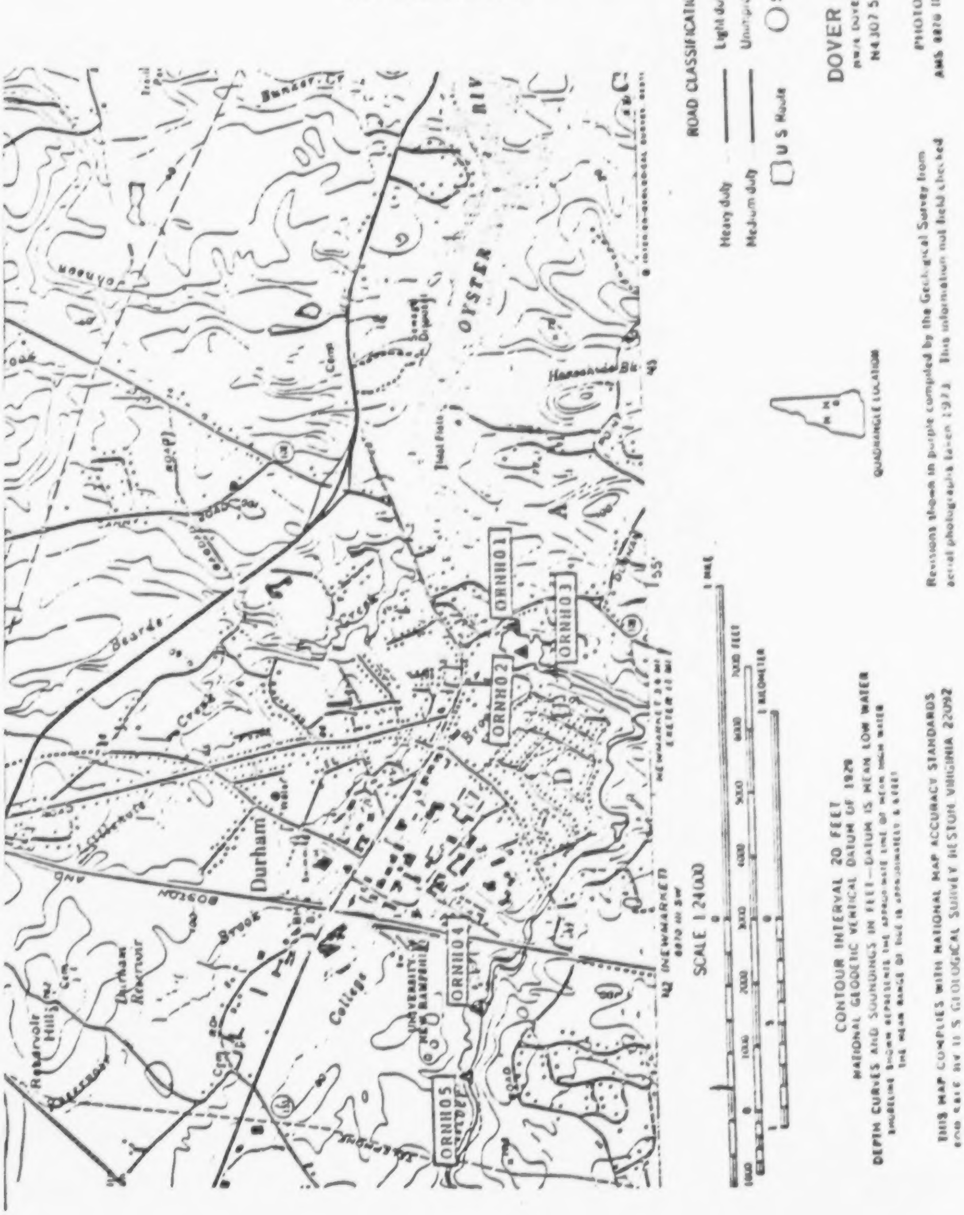

ORNH01
ORNH02
ORNH03
ORNH04
ORNH05
OYSTER
RIV
Durham
Durham Reservoir
Reservoir Hill
College
Brook
Beards
Creek
Johnson
Bunker Cr
BOSTON AND
ROAD CLASSIFICATION
Heavy duty
Medium duty
Light duty
Unimproved dirt
U S Route
State Route
QUADRANGLE LOCATION
SCALE 1:24000
1 MILE
0
1 KILOMETER
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, RESTON, VIRGINIA 22092
Revisions shown in purple compiled by the Geological Survey from aerial photographs taken 1973. This information not field checked
DOVER WEST, N. H.
N4307.5—W7052.5/7.5
1956
PHOTOREVISED 1973
AMS 6870 III NW—SERIES V812

TABLE 24

OYSTER RIVER SOD AND SEDIMENT METALS SAMPLING STATIONS

(see figure 6)

	Sampling Station				
	Mill Pond			Durham Water Supply	
Parameter	ORNH01	ORNH02	ORNH03	ORNH04	ORNH05
Mean SOD Rate $gmO_2/M^2/day$	3.82	2.94	4.52	2.73	5.91
±Std. Error (5 replicates)	±0.27	±0.34	±0.43	±0.22	±0.57
% Solids by wt.	47.4	41.2	43.3	35.3	36.3
% Volatile	7.72	10.4	9.72	9.19	11.1
Metals µg/gm					
Mn	383	381	314	475	540
Cr	33	37	29	28	27
Cu	32	65	28	86	58
Zn	138	166	120	120	120
Cd	1	2	1	1	1
Pb	50	120	40	30	40

*Samples collected 13-17 July 1981.
Complete report appears in Appendix

7-Oys, but more pronounced at 5-Oys.

Solids data from SOD cores reflect an overall greater percentage of solids by weight in Mill Pond than in the water supply reservoir. However, percentages of volatile solids in the sediment cores do not correlate with SOD rates observed.

Results of metal analyses from SOD cores indicate routinely higher concentrations of chromium, zinc, and lead in Mill Pond compared with concentrations encountered in the water supply reservoir. Mean lead concentrations in Mill Pond were 70 g/mg versus 35 g/mg in the reservoir. This relative difference is the largest observed between the two locations. Considering the greater acreage of drainage area contributing to the water supply reservoir compared with Mill Pond (10,560 versus 2,181 acres) and the fact that ambient lead concentrations are routinely less than detectable limits (<0.005 mg/l) in river water discharged from the reservoir, it is reasonable to assume that considerable lead loadings are generated as a result of urbanization in the 5-Oys drainag basin.

Sampling station ORNH02 is located in Mill Pond near the mouth of College Brook, which receives drainage from the most urbanized areas in Durham. It is interesting to note that metals data from SOD chores collected at this station show the highest concentrations of chromium, zinc, cadmium, and lead.

Summary

In-stream dry weather water quality conditions have been shown to decline significantly as a result of stormwater runoff in both the Oyster River and Pettee Brook.

Comparison of water quality between upstream and downstream sampling stations in Pettee Brook have suggested the existence of waste discharge in the reach. Similar analyses in the Oyster River show a trend of decreased concentrations between stations. These results indicate settling and perhaps other attenuating mechanisms are active in the Mill Pond Impoundment.

Water Quality Standards and Criteria Violations

To augment the existing "White Book" water quality criteria for toxic substances (Environmental Protection Agency, 1980), members of the Environmental Protection Agency Nationwide Urban Runoff Program (NURP) Headquarters staff and the NURP consultant team have established additional standards for selected toxics which address the relatively short exposure regimes associated with storm-generated pollutant loads. Those criteria, along with numerical standards for total coliform bacteria and turbidity which have been established by the New Hampshire State Legislature, are presented in Table 25. Durham NURP water quality data have been analyzed with respect to these criteria.

It should be recognized that not all seven impact categories presented in Table 25 apply at each station. For example, the drinking water standards would apply to upstream Oyster River (7-Oys) only. Similarly, the saltwater aquatic life criteria do not apply to any Durham NURP station, and parking lot (1-Pkg) data are end-of-pipe, to which no receiving stream water quality criteria apply. However, the analysis provides a useful yardstick in evaluating potential impacts and permits extrapolation of NURP data to other receiving water types.

The criteria presented for metals are based upon a receiving water hardness of 50 mg/l (as $CaCO_3$), which is typical of concentrations encountered in the study area. Due to low hardness, effective toxicity results from extremely low metal concentrations. Since concentrations below routine analytical detection limits may still result in toxicity, the metals data analysis presented below (Table 26 and accompanying figures) is conservative. This problem is of particular concern when dealing with the copper data generated during Phase I of this study. The routine analytical detection

TABLE 25

WATER QUALITY STANDARDS FOR NURP DATA ANALYSIS

EPA STANDARDS (All concentrations in milligrams/liter, mg/l)

Contaminant	Freshwater Aquatic Life		Saltwater Aquatic Life		Human Ingestion	NURP Estimated Effect Level fo Intermittent Exposure	
	24 hr	Max	24 hr	Max		Threshold	Significant Impact
Copper	0.0056	0.012	0.004	0.023	N.P.	0.1	0.2
Zinc	0.047	0.18	0.058	0.17	N.P.	0.4	0.8
Lead	0.00075	0.074	(0.025) (C)	0.670 (A)	0.050	2.5	4.5
Cadmium	0.00001	0.0015	0.0045	0.059	0.010	5.0	10.0
Nickel	0.056	1.09	0.0071	0.140	0.0134	-	-

NOTES:

- These toxic criteria are based upon receiving water total hardness of 50 mg/l (as $CaCO_3$).
- Concentration values shown within parenthese ( ) are not formal criteria values. They reflect either chronic (C) or acute (A) toxicity concentrations which the EPA toxic criteria document indicated have been observed. Values of this type were reported where the data base was insufficient (according to the formally adopted guidelines which were used developing the criteria) for EPA to develop 24 hour and Max values.
- Note (1): The "Human Ingestion" criteria developed by the EPA Toxic Criteria documents are indicated to relate to ambient receiving water quality. The Drinking Water Criteria relate to finished water quality at the point of delivery for consumption.
- Estimated Effects levels reflect estimates of the concentration levels which woud impair beneficial uses under the kind of exposure conditions which would be produced by Urban Rur They are an estimate of the relationship between continuous exposure and intermittent, shc duration exposures (several hours once every several days).
- NP = No criteria proposed.

NEW HAMPSHIRE STANDARDS

	Class A	Class B	Class C
Dissolved Oxygen	Not less than 75% of saturation, nor less than 6 mg/l	Not less than 75% of saturation, nor less than 6 mg/l	Not less than 6 mg/l
Coliform Bacteria	50/100 ml sample	240/100 ml sample freshwater 70/100 ml for saltwater	1000/100 ml sample (log average value or 2500/100 ml sample for any single sample
Turbidity (Std units)	5	10	10

limit of 0.1 mg/l is equal to the threshold aquatic life toxicity level established by the NURP consultants. Since most data returned from the laboratory were reported as less than 0.1 mg/l copper, no estimation of impacts below threshold toxicity was possible.

Table 26 summarizes the magnitude of standards violations at each station by presenting the percentage of samples (dry weather or storm runoff) which violate any of the seven target impact categories in Table 25.

Note that for each constituent addressed, standards are violated with generally greater probability at the downstream stations when compared to the upstream stations. Also, note the considerably higher probability of violations during storm runoff compared with dry weather samples.

Pettee Brook

As reflected in Table 26, New Hampshire Class B (fishable/swimmable) total coliform bacteria standards violations are widespread at both upstream and downstream Pettee Brook stations during both dry and wet weather. Since the total coliform bacteria test frequently includes non-enteric organisms, the fecal coliform test is commonly used to better estimate the probable source and severity of fecal contamination. The New Hampshire State Legislature has not set standards for fecal coliform. For the purposes of this analysis, a concentration of 200 per 100 ml of sample has been arbitrarily set as the fishable/swimmable standard. Probability analysis of Pettee Brook fecal coliform data has been used to generate the summary statistics presented in Table 27. Note the overall greater degree of contamination at the downstream station and the dramatic increase in storm concentrations over dry weather concentrations.

Turbidity samples were collected only for storm events in Pettee Brook. Both upstream and downstream stations violated the Class B New Hampshire Water

TABLE 26

Percent of Samples Violating Water Quality Standard*

Constituent		Pettee Brook				Oyster River				Parking Lot	
		3-Pte (Upstream)	# Obs	2-Pte (Downstream)	# Obs	7-Oys (Upstream)	# Obs	5-Oys (Downstream)	# Obs	1-Pkg	# Obs
Cadmium	Dry Weather	0	9	0	7	18	11	11	9	-	-
	Storm Water	13	16	6	16	0	20	6	18	4	28
Copper	Dry Weather	0	9	0	7	0	11	0		-	-
	Storm Water	11	18	0	17	0	19	0	18	14	31
Lead	Dry Weather	0	9	14	7	9	11	0	9	-	-
	Storm Water	83	18	89	18	10	20	6	18	97	33
Zinc	Dry Weather	0	9	0	7	0	11	0	0	-	-
	Storm Water	89	18	96	18	75	20	67	18	100	33
Total Coliform (Class B)	Dry Weather	91	11	100	12	67	15	69	13	-	-
	Storm Water	100	12	100	11	44	16	100	14	95	20
Fecal Coliform (200/100 ml sample)	Dry Weather	18	11	50	12	0	15	8	13	-	-
	Storm Water	83	12	100	11	44	17	82	15	70	20
Turbidity	Dry Weather	-	-		-	-	-	-	-	-	-
	Storm Water	100	9	90	10	23	13	28	14	82	11

*Standards are based upon criteria established by EPA (for metals) and NHWS&PCC (total coliform and turbidity). There are no established standards for fecal coliform. For comparison among stations, a concentration of 200 cts/100 ml sample has been arbitrarily selected.

TABLE 27

Pettee Brook

Coliform Bacteria Data Summary

Total Coliform Bacteria (MPN/100 ml)

	Dry Weather Data		Storm Runoff Data	
	3-Pte	2-Pte	3-Pte	2-Pte
10th Percentile	300	360	1,350	15,000
50th Percentile	1,400	1,900	40,000	71,000
90th Percentile	6,600	9,600	110,000	250,000
Probability ≥200/100 ml sample	95%	97%	98%	100%
# Observations	11	12	12	11

Fecal Coliform Bacteria (MPN/100 ml)

	Dry Weather Data		Storm Runoff Data	
	3-Pte	2-Pte	3-Pte	2-Pte
10th Percentile	7	42	90	500
50th Percentile	62	160	1,800	3,200
90th Percentile	530	620	35,000	22,000
Probability ≥200/100 ml sample	24%	42%	83%	100%
Fecal Coli./Fecal Strep.	0.97	0.89	0.84	0.92
# Observations	11	12	12	11

Quality Criteria in nearly all samples.

Figure 7 presents probabilities of water quality criteria violation for metals in samples collected during both dry weather and stormwater runoff in the Pettee Brook catchment. Results for each metal displayed show storm-related increases over dry weather violations at both upstream and downstream stations.

Perhaps the most meaningful violation categories are those developed by the NURP consultants which address intermittent exposure periods associated with stormwater runoff events. Note that copper is the only constituent which violates the NURP criteria for threshold biological effects. Although several of the metals addressed in this analysis show pronounced concentration increases as a result of stormwater runoff influences, copper may well be the only metal which significantly impacts Pettee Brook water quality, albeit on an infrequent basis (11% of samples).

An unexpected trend of comparatively high water quality constituent concentrations at the upstream Pettee Brook station is evident in Figure 7. Less overall standards violations were anticipated at 3-Pte than were actually encountered. Although the frequency of standards violations is generally greater downstream, dry weather and storm samples collected upstream at 3-Pte show routinely higher concentrations than expected, considering the rural nature of the drainage area.

Late summer 1980, a piped discharge from the University swimming pool filter backwash system was discovered immediately upstream of 3-Pte, which is presumed responsible for the poor water quality measured at this station.

Table 28 presents water quality data for samples collected at 3-Pte which coincided with filter backwashing activity. The summary presented in Table 26

FIGURE 7

PETTEE BROOK METALS CRITERION VIOLATIONS

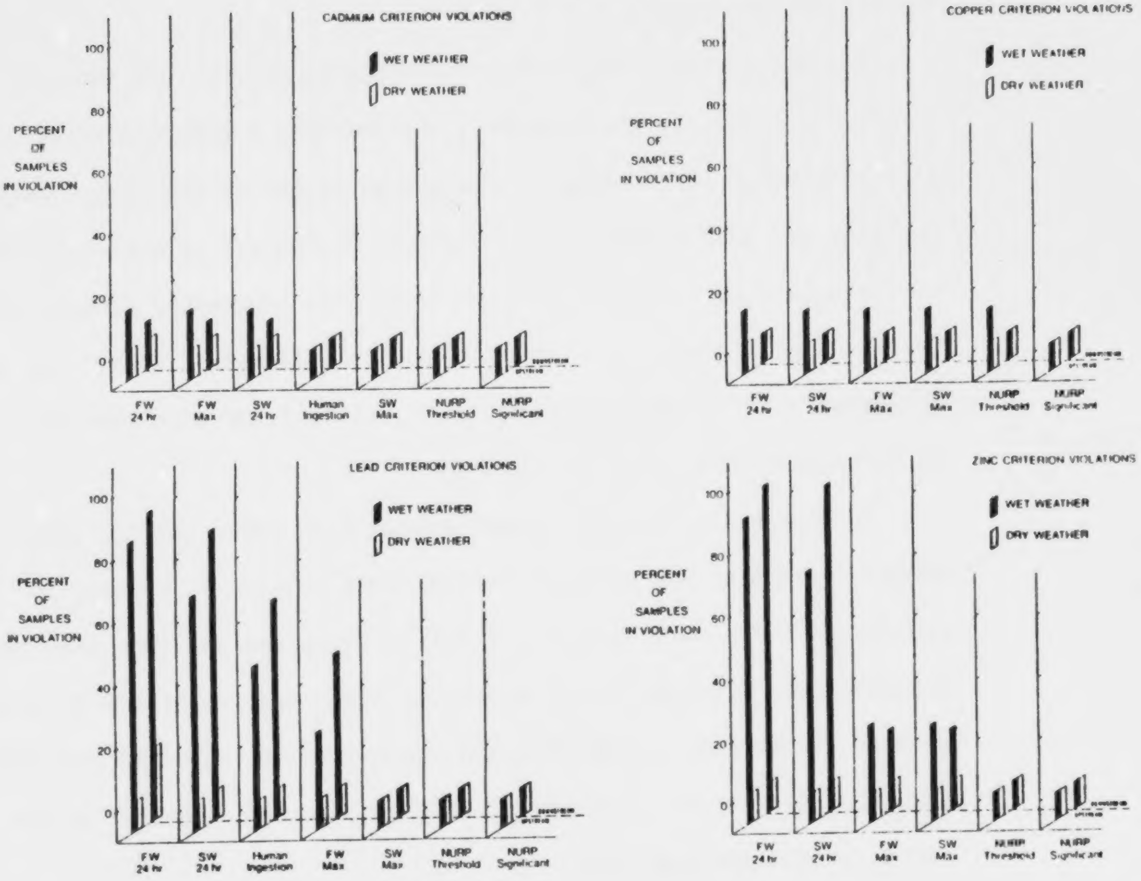


TABLE 28

Pool Discharge Influenced Water Quality Data*
Upstream Pettee Brook - 13 August 1980

Spec. Cond., MHOs	741
pH, std. units	7.5
Alkalinity	62.1
Solids, Total	642
Solids, Susp.	25
NH_3	<0.10
PO_4	0.024
P	>0.31
Mg	5.4
Mn	4.8
Cd, total	<0.005
Cr, total	0.02
Cu, total	12.0
Fe, total	25.0
Pb, total	0.07
Zn, total	0.42
Tot. Coli MPN/100 ml	<50
Fec. Coli MPN/100 ml	<5

*All units mg/l unless specified

does not include samples suspected to be influenced by this discharge to Pettee Brook.

To what extent this discharge influences Pettee Brook stormwater quality (3-Pte and 2-Pte) remains unclear due to complexing factors such as the irregular frequency of filter backwashing activity and variable settling rates of discharged material followed by resuspension during storm runoff scouring.

Review of data collected throughout the study period suggests that Pettee Brook data collected between June 15 and August 30 (1980 and 1981) are heavily influenced by filter backwash. Thus, nearly all summertime data, which is the most critical period of stormwater influence due to increased receiving water temperatures and decreased base flow, are limited in terms of defining urban runoff influences. Since water quality may be influenced by storm flow sediment resuspension well beyond August 30, data collected over the period September through December are also questionable.

As an aid to the interpretation and evaluation of urban runoff effects, the NURP consulting team has developed a method to estimate time-frequency of criteria violation recurrence intervals. This method is described at length in Volume II of the "Preliminary Results of the Nationwide Urban Runoff Program," Environmental Protection Agency, March 1, 1982. In applying this analysis to Durham data, a storm frequency of 130 per year has been used (NOAA; historical records for Boston, Mass.).

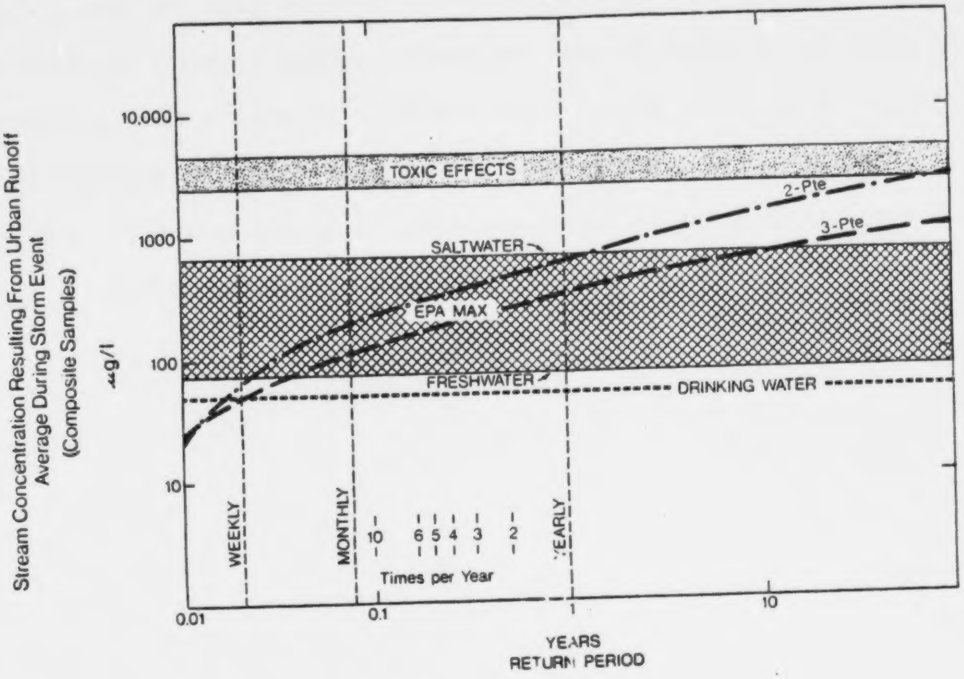
Lead and zinc concentration data have been shown to exhibit a log normal frequency distribution. Although cadmium and copper concentrations likely exhibit some degree of variability which could be characterized, the laboratory analytical detection limit is well above the routine range of this variability. Hence, the time-frequency of recurrence analysis could not be applied.

Figure 8 presents the results of this analysis for lead and zinc data collected in Pettee Brook. Freshwater maximum criteria for both metals can be expected to recur several times monthly. Stormwater zinc concentrations high enough to elicit toxic effects in Pettee Brook can be expected to recur at intervals of eight to fourteen months. Lead concentrations high enough to cause toxic effects are not to be expected in Pettee Brook.

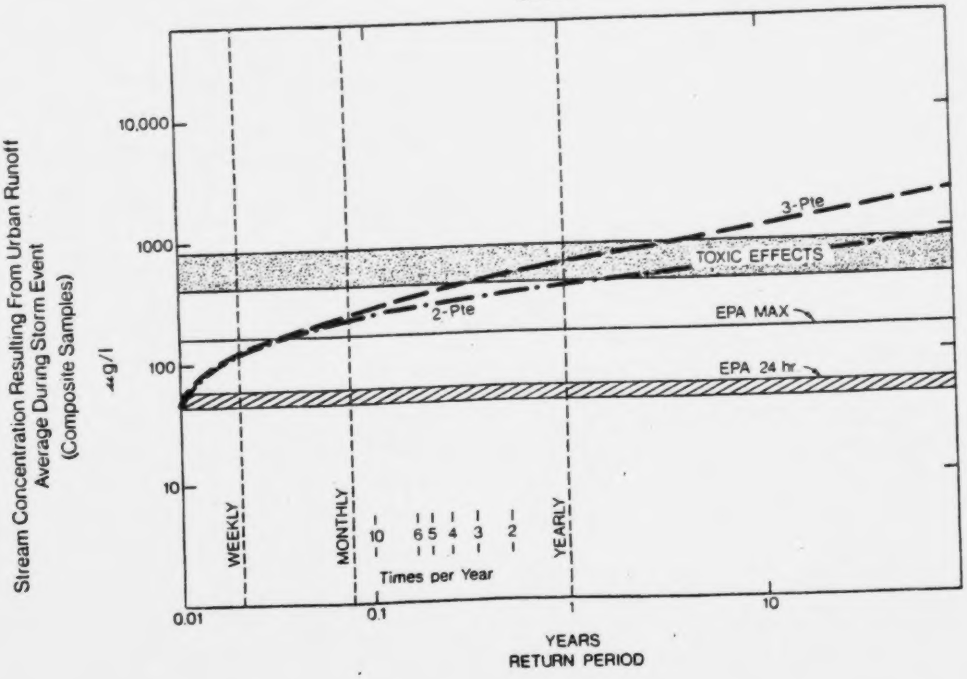
FIGURE 8

RETURN PERIOD OF PETTEE BROOK METALS CRITERION VIOLATIONS

LEAD



ZINC



Oyster River

Total coliform bacteria standard violations were more frequent in storm samples than in dry weather samples collected in the Oyster River; however, only moderately so at the upstream site in comparison with the downstream station, where one hundred percent of samples were in violation. Table 29 summarizes Oyster River coliform data.

Fecal coliform data for the Oyster River are also summarized in Table 29. As with total coliform data discussed above, there is an obvious storm-generated increase between the upstream and downstream stations, although the degree of contamination is significant at both stations. Ratios of fecal coliform to fecal streptococci indicate non-human sources of contamination. Dry weather samples are relatively free of fecal coliforms at both Oyster River stations.

As with Pettee Brook, only storm samples were collected for turbidity analyses. As presented in Table 26, there is little difference between the two stations in the percentages of samples violating the New Hampshire Water Quality Class B standard for turbidity.

Figure 9 details Oyster River metals water quality criteria violations for each of the seven target impact categories presented in Table 25. Overall, metals concentrations were quite low at both Oyster River stations. Marked increases in stormwater over base flow concentrations demonstrate the influence of lead and zinc stormwater levels; however, concentrations high enough to impact the threshold for toxic effects were rarely encountered for zinc and not at all for lead. Results for copper and cadmium show very low frequencies of standards violations, with basically no difference in dry weather and stormwater samples.

TABLE 29

Oyster River

Coliform Bacteria Data Summary

Total Coliform Bacteria

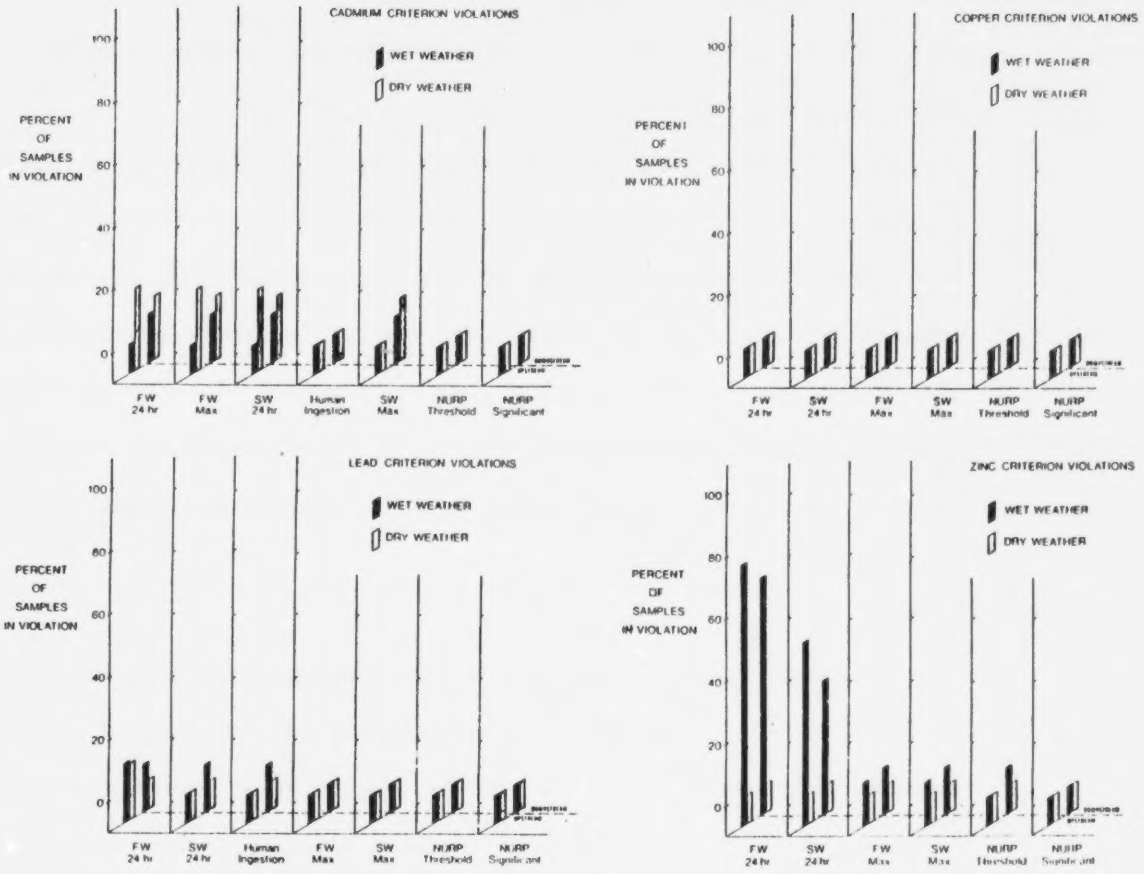
	Dry Weather Data		Storm Runoff Data	
	7-Oys	5-Oys	7-Oys	5-Oys
10th Percentile	60	68	17	1,400
50th Percentile	430	400	680	11,000
90th Percentile	2,800	2,300	26,000	90,000
Probability ≥200/100 ml sample	31%	31%	33%	100%
# Observations	17	17	16	14

Fecal Coliform Bacteria

	Dry Weather Data		Storm Runoff Data	
	7-Oys	5-Oys	7-Oys	5-Oys
10th Percentile	7	5	4	100
50th Percentile	27	24	145	600
90th Percentile	110	120	2,600	3,500
Probability ≥200/100 ml sample	3%	4%	44%	82%
Fecal Coli./Fecal Strep.	0.96	0.94	0.83	0.92
# Observations	18	18	17	14

FIGURE 9

OYSTER RIVER METALS CRITERION VIOLATIONS



As with Pettee Brook metals data, only lead and zinc concentrations exhibited enough variability to allow a meaningful time-frequency of recurrence analysis. Figure 10 depicts the results of this analysis. Environmental Protection Agency criteria for maximum allowable freshwater lead concentrations are exceeded approximately four times per year at the downstream station compared with approximately five-year intervals at the upstream station. The greater frequency of criteria violations in the downstream catchment reflects the influence of urbanization on Oyster River lead concentrations; however, concentrations high enough to cause lead toxicity in the Oyster River are not to be expected.

Toxicity resulting from stormwater zinc concentrations is rarely expected in the Oyster River, recurring at intervals of greater than one year. Environmental Protection Agency maximum exposure criteria are exceeded with regularity, approximately eight times yearly. Although stormwater zinc concentrations are significantly greater than base flow concentrations, as shown in Figure 9, these elevations cannot be attributed to urbanization since there is no discernible difference between upstream and downstream stormwater zinc violation frequencies.

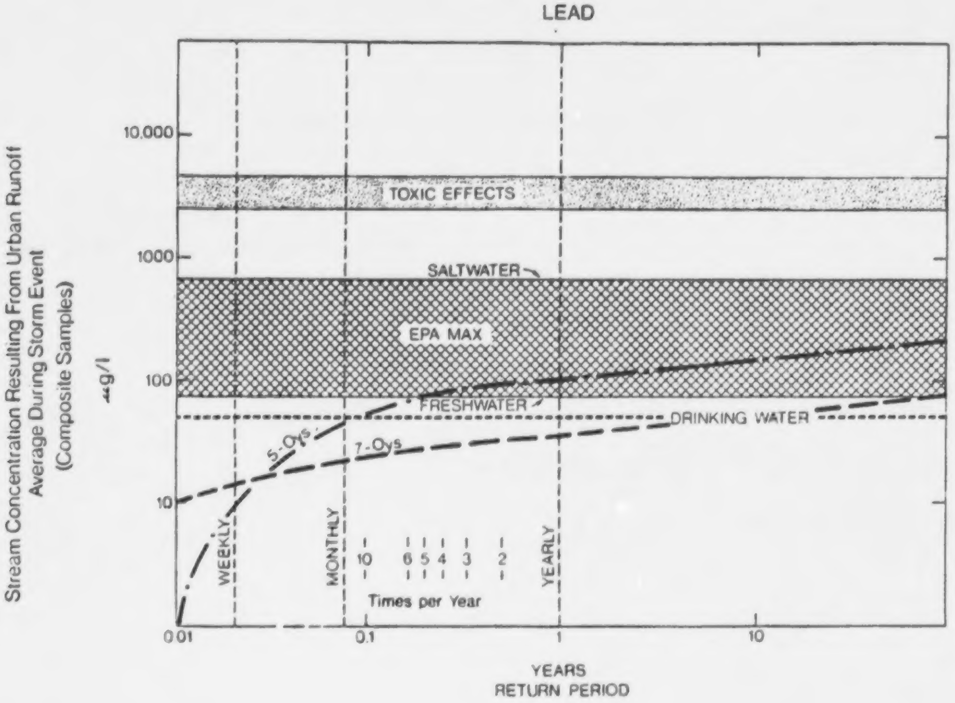
1-Pkg

Stormwater runoff from the 0.8 acre commercial parking lot study area was by far the most contaminated by urban development. It should be noted, however, that runoff from this site is sampled at an end-of-pipe location, before dilution of the receiving streams. All other sampling stations were located in-stream.

Table 30 presents the frequency distribution of coliform bacteria in parking lot stormwater runoff. Severe total and fecal coliform contamination is indicated.

FIGURE 10

RETURN PERIOD OF OYSTER RIVER METALS CRITERION VIOLATIONS



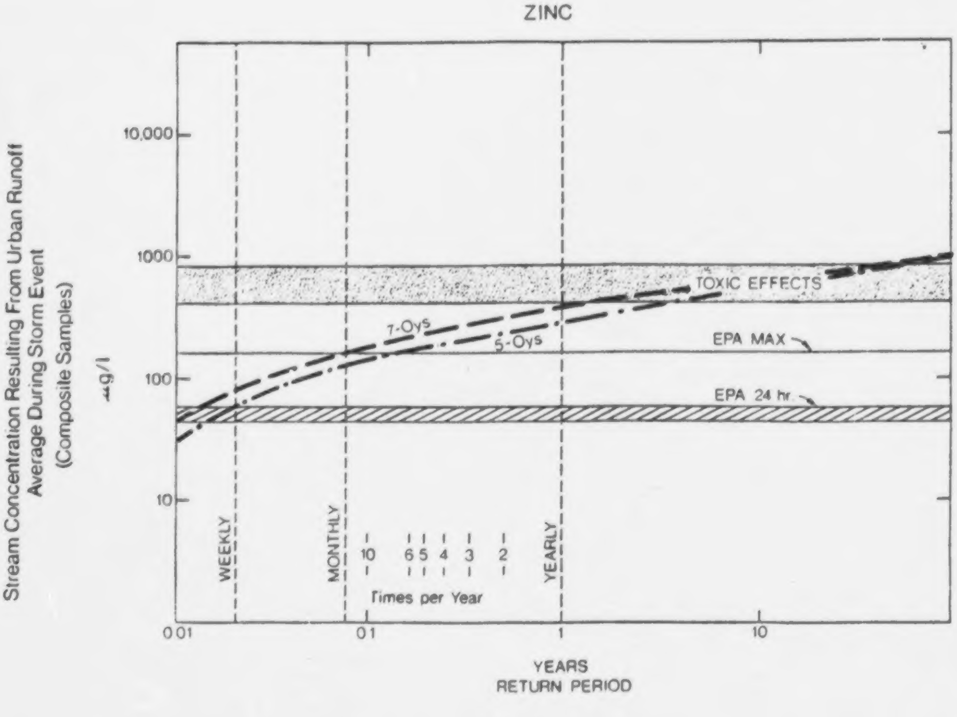


TABLE 30

Parking Lot

Coliform Bacteria Data Summary

	Stormwater	
	Total Coliform	Fecal Coliform
10th Percentile	15,500	15
50th Percentile	150,000	1,200
90th Percentile	4,000,000	96,000
Probability ≥ 200 cts/100 ml Sample	100%	70%
Number Observations	20	20

Recognizing the limited value of copper data generated during Phase I of this study, special laboratory arrangements were made to provide a lowered detection limit of 0.03 mg/l for Phase II sampling. Copper data collected at the parking lot site during Phase II have been incorporated into the Phase I data base for the following impact analysis.

Figure 11 summarizes violations of metals criteria presented in Table 25. As indicated, concentrations of zinc and, to a lesser extent, copper violated the NURP toxicity categories. Also, note that lead concentrations great enough to violate the Environmental Protection Agency freshwater maximum criteria were encountered in nearly ninety percent of samples collected.

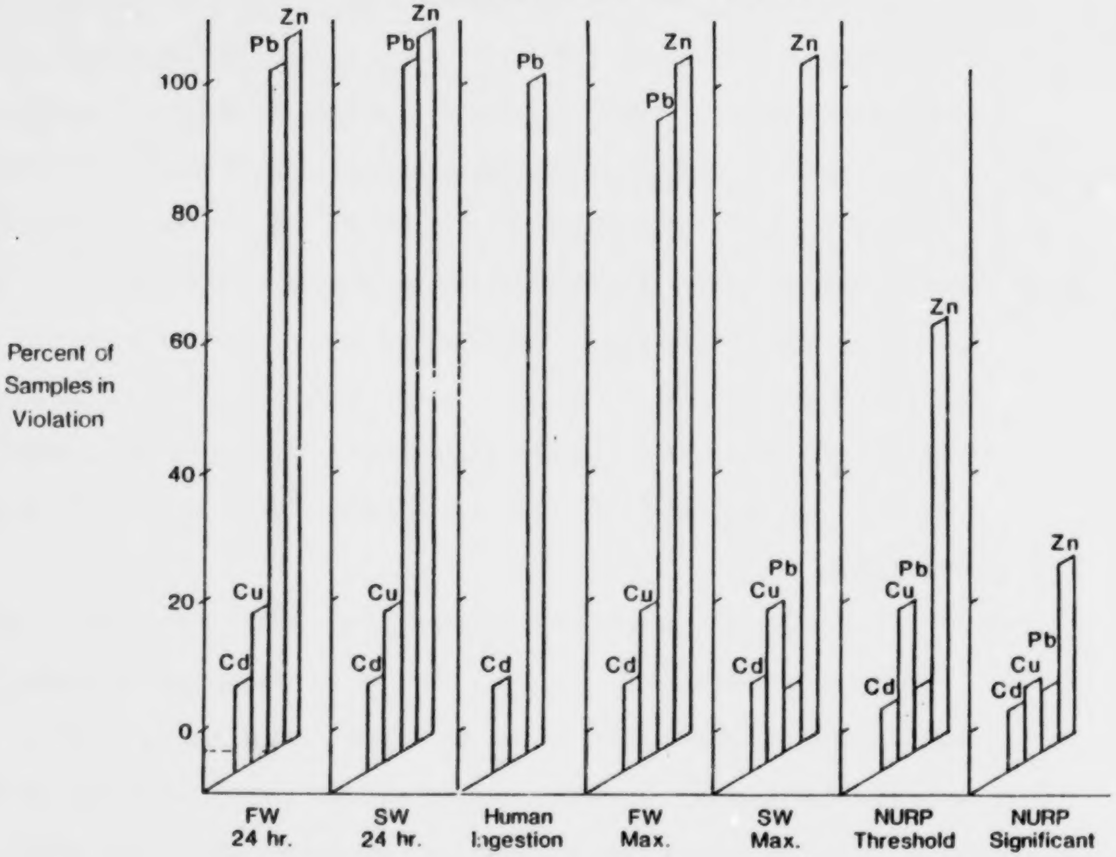
As discussed previously, modifications to the parking lot site included installation of galvanized line drains to isolate runoff contributions from the study area. These drains are presumed to contribute significantly to the observed high zinc concentrations in the runoff. It must also be noted, however, that galvanized drainage structures are quite commonly used, therefore, the potential for high zinc concentrations also exists in other urban areas.

Figure 12 presents the time-frequency of violation recurrence analysis for parking lot metals criteria. Violations of Environmental Protection Agency maximum freshwater criteria for copper, lead, and zinc can be expected several times weekly. As with the case in both the Oyster River and Pettee Brook, zinc can be expected to reach concentrations within the range of toxicity defined by the NURP consultants within a reasonable recurrence interval. In addition, parking lot runoff copper concentrations can be expected to reach toxic levels on a monthly basis.

FIGURE 11

PARKING LOT

METALS CRITERION VIOLATIONS



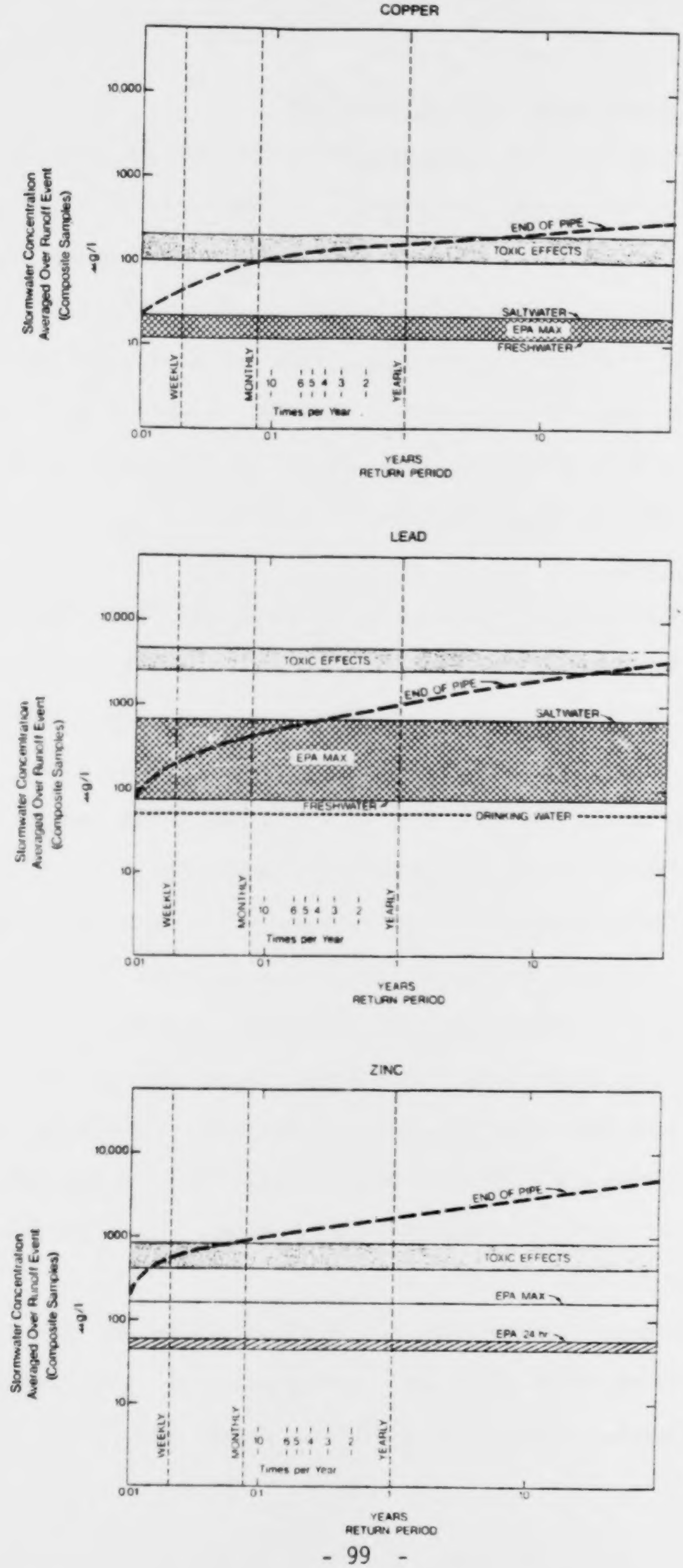


FIGURE 12
RETURN PERIOD OF
PARKING LOT
METALS CRITERION VIOLATIONS

Runoff Event Water Quality Variations

The parking lot site, downstream Pettee Brook (2-Pte), and downstream Oyster River (5-Oys) were selected for intensive discrete stormwater sampling to address the variability of constituent concentrations over the course of stormwater runoff events in the more urbanized catchments. Data presented for these stations and the other two catchments (3-Pte and 7-Oys) in Tables 11-13 include samples which were collected during routine weekly sampling and later determined to be influenced by previous storm events, as well as the intensive storm sampling discussed below.

Parking Lot

Discrete sampling of two storm events at the parking lot site is summarized in Tables 31 and 32. These results reveal a characteristic "first flush" for most pollutant concentrations, consistent with literature reports (Black, 1980; Whipple and Hunter, 1977). Figure 13 clearly demonstrates this phenomenon for COD, solids, lead, zinc, phosphorus, and nitrogen species.

Discrete stormwater sampling conducted during one storm in the downstream Pettee Brook and Oyster River catchments is summarized in Tables 33 and 34. These results do not suggest the consistent rapid "first flush" washoff of pollutants as demonstrated at the parking lot site.

Figure 14 presents Pettee Brook results for the constituents presented above. Whereas phosphorus and nitrogen species exhibited a definite "first flush," lead and zinc certainly did not. Total solids appear to have reached maximum concentration concurrently with peak flow rate, and no trend can be defined for COD.

As shown in Figure 15, Oyster River results are even less definitive with no apparent trends other than the concurrent peaks of lead and flow rate. Unfortunately, samples for nutrient analyses were not collected.

Discrete stormwater runoff samplng in both the Pettee Brook and Oyster River catchments reflect the influence of basin detention time and multiple location contaminant inputs to larger receiving streams. Also, the need for source control of stormwater runoff before entering the receiving stream is clearly indicated in the parking lot results. The benefit of capturing the initial runoff for treatment is obvious, particularly where sizing requirements of structural control measures become prohibitive, and where toxic in-stream concentrations may result due to little dilution in the receiving stream.

TABLE 31
PARKING LOT DISCRETE STORMWATER DATA SUMMARY*
STORM OF 29 JULY 1980

Time	Flow Rate (cfs)	BOD	TS	TSS	NH_3	NO_2+ NO_3	Total P	Fe	Pb	Mg	Na	Zn	pH (std.) (units)	Conductivity (umhos)
1340	0.10	76	336	40	1.7	1.55	>0.31	2.5	0.74	2.2	7.9	1.49	3.7	221
1420	0.15	34	144	16	0.62	0.72	>0.31	1.2	0.39	1.0	3.1	0.70	3.8	125
1435	0.15	38	70	10	0.24	0.31	0.158	0.7	0.20	0.69	1.6	0.28	4.0	70
1450	0.18	28	50	11	<0.1	0.19	0.122	0.5	0.15	0.60	1.6	0.22	4.1	51
1455	0.2	28	39	6	<0.1	0.14	0.083	0.6	0.10	0.44	1.1	0.13	4.2	38
1510	0.15	20	30	9	<0.1	0.10	0.064	0.6	0.10	0.46	1.2	0.13	4.3	33
1535	0.15	30	29	4	<0.1	0.13	0.063	0.4	0.10	0.49	1.3	0.13	4.3	34
1630	0.06	28	68	10	0.72	0.27	0.095	0.8	0.24	0.78	1.7	0.51	4.0	72
1825	0.16	16	120	63	0.28	0.43	0.193	2.2	0.30	1.07	2.0	0.35	4.2	61
1840	0.12	26	65	40	0.19	0.22	0.108	0.9	0.15	0.67	1.7	0.17	4.2	32
1850	0.20	22	54	44	0.17	0.14	0.99	0.9	0.10	0.67	1.5	0.13	4.6	21
1910	0.24	25	54	25	0.16	0.10	0.078	0.9	0.10	0.57	1.2	0.11	4.7	16
1915	0.20	24	48	28	0.16	0.08	0.57	0.09	0.09	0.59	1.2	0.29	4.7	16
1920	0.24	25	47	25	0.18	0.08	0.120	0.8	0.08	0.71	1.5	0.10	4.7	16
1930	0.24	32	24	12	0.21	0.08	0.270	0.4	0.5	0.41	0.9	0.09	4.7	16
1940	0.32	16	36	20	0.19	0.08	0.310	0.4	0.06	0.51	1.0	0.20	4.7	16
1950	0.22	14	26	12	0.22	0.08	0.027	0.4	0.05	0.43	0.9	0.08	4.7	18
1955	0.18	14	31	5	0.25	0.11	0.21	0.3	0.05	0.42	1.2	0.09	4.6	20
-	0.20	8	34	8	0.27	0.11	0.018	0.4	0.06	0.71	1.4	0.57	4.6	23
2005	0.14	12	27	3	0.24	0.09	0.017	0.3	0.05	0.43	0.4	0.09	4.6	20
2035	0.12	8	24	1	0.22	0.09	0.003	0.1	0.04	0.12	0.4	0.9	4.6	19
2040	0.12	10	21	0	0.17	0.08	0.010	0.1	0.3	0.11	0.6	0.09	4.7	16
2120	0.04	10	26	2	0.27	0.10	0.010	0.1	0.04	0.11	0.6	0.09	4.6	23
2210	0.08	10	23	2	0.21	0.15	0.024	0.2	0.05	0.45	1.3	0.12	4.6	21

*All units ms/l unless specified.

TABLE 32

PARKING LOT DISCRETE STORMWATER DATA SUMMARY

Storm of 8/5/80 (Discrete Sampling)
Pollutant Concentrations, Shop 'n Save Parking Lot
(mg/l)

Sample	Flow Rate (cfs)	BOD	COD	TS	TSS	NO_2+ NO_3	PO_4	Total P	Fe	Mg	Mn	Na	Sn	Zn	pH (units)	conductivity (umhos)
1	0.88	32	174	254	124	0.92	0.003	0.004	3.8	1.59	0.21	8.0	0.28	0.80	5.9	122
2	0.92	24	103	156	80	1.06	.002	0.003	2.5	1.23	0.15	3.8	0.13	.68	5.1	72
3	0.92	10	64	111	80	0.89	0.001	--	2.2	0.77	0.11	2.1	0.16	.52	5.1	61
4	0.96	22	60	80	56	0.74	0.002	0.033	1.5	0.53	0.17	1.4	0.14	0.37	5.0	40
5	1.12	18	40	89	78	0.64	0.003	0.121	2.1	0.78	0.08	1.9	0.15	0.33	5.0	33
6	0.96	18	30	57	43	0.69	0.001	0.018	1.0	0.35	0.06	1.0	0.13	0.34	4.8	29
7	0.96	14	20	49	47	0.53	0.003	0.083	1.2	0.38	0.06	1.0	0.06	0.25	4.9	25
8	0.92	8	32	64	48	0.50	0.005	0.061	1.4	0.51	0.06	1.4	0.13	0.27	5.0	24
9	0.88	12	56	49	29	0.52	0.003	0.025	0.8	0.43	0.04	1.3	0.13	0.25	4.8	27
10	0.04	16	60	--	--	.79	0.006	0.045	0.8	0.43	--	--	--	--	6.1	--

*All units mg/l unless specified

FIGURE 13
PARKING LOT DISCRETE STORMWATER DATA
STORM OF 29 JULY 1980

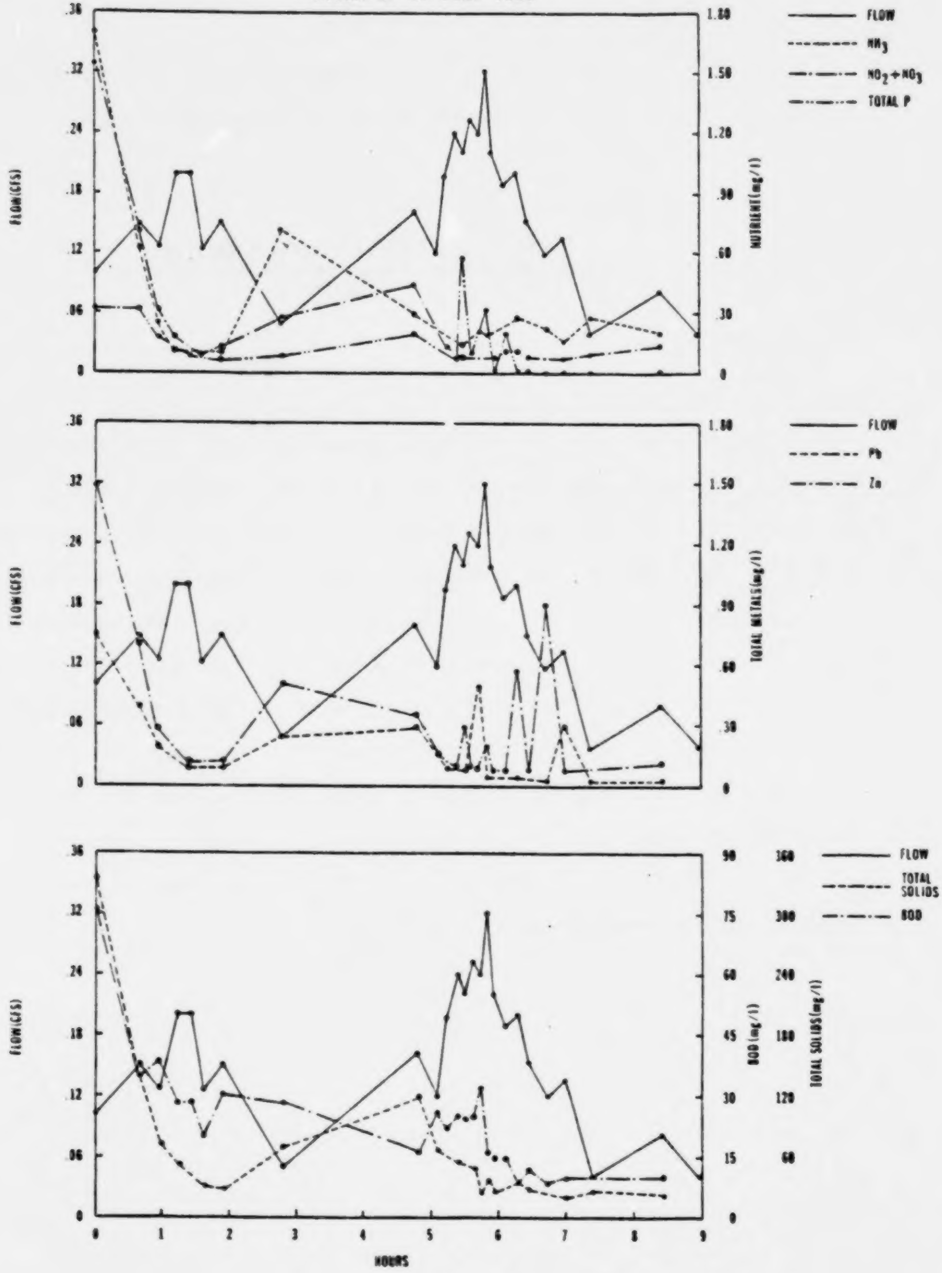


TABLE 33

DISCRETE STORMWATER DATA SUMMARY
DOWNSTREAM PETTEE BROOK
STORM OF 29 JULY 1981

Time	(cfs)	BOD	COD	Total Solids	Susp. Solids	NH_3	NO_2 NO_3	P	PO_4	Fe	Pb	Zn	Cl	Total Coli	Fecal Coli	Spec. Cond	pH
0200	3.6	4.0	56	222	31	0.28	0.84	1.02	0.084	2.1	0.020	0.07	55	140,000	2300	35	7.0
0345	4.0	3.2	16	166	1	0.40	0.90	1.20	0.076	2.2	0.015	0.03	40	39,000	3900	178	7.2
0452	7.1	4.0	20	155	50	0.29	0.72	-	0.071	3.7	0.025	0.04	21	150,000	9300	140	7.1
0545	11.9	3.2	36	297	193	0.14	0.47	-	0.068	1.9	0.025	0.04	16	150,000	4300	80	6.9
0630	7.6	2.6	24	196	41	<0.10	0.37	0.07	0.051	0.8	0.040	0.08	10	40,000	9300	76	6.9
0700	5.0	2.8	28	147	13	<0.10	0.40	0.09	0.058	0.8	0.060	0.16	17	43,000	4300	132	7.2
0800	5.7	2.0	32	134	1	<0.10	0.37	0.10	0.045	1.0	0.130	0.17	16	930	40	126	7.1
1030	5.3	1.8	44	165	23	0.10	0.35	0.14	0.057	1.9	0.010	0.03	31	43,000	4300	216	7.0

TABLE 34

DISCRETE STORMWATER DATA SUMMARY
DOWNSTREAM OYSTER BROOK
STORM OF 29 JULY 1981

Time	(cfs)	BOD	COD	TS	TSS	Fe	Pb	Zn	Cl	Tot. Coli	Fec. Coli	Spec. Cond.	pH
0300	14.9	2.8	32.0	132	1.0	1.1	<0.01	0.02	32	4300	90	183	7.1
0600	24.5	0.4	39.8	114	5.0	1.1	<0.01	0.02	28	3900	2300	179	7.3
0900	22.0	3.4	20.0	130	1.0	1.2	<0.01	0.02	30	430,000	4300	177	7.6
1200	22.0	1.2	36.0	109	1.0	1.0	<0.01	0.05	27	4300	3300	175	7.0
1500	22.0	0.8	40.0	111	4.0	0.8	<0.01	0.04	27	3300	930	177	7.4
1800	29.0	1.6	40.0	111	4.0	1.0	<0.01	0.02	27	4300	3300	181	7.1
2100	32.5	0.8	36.0	107	2.0	0.9	0.015	0.04	27	9300	1500	177	7.3
2400	36.3	1.2	36.0	108	1.0	1.0	0.015	0.03	28	15,000	9300	179	7.4
0300	32.5	0.2	32.0	115	4.0	1.1	0.010	0.04	29	7500	2300	189	7.3
0600	29.0	1.0	58.0	129	1.0	1.1	0.010	0.03	30	4300	30	181	6.9

FIGURE 14
PETTEE BROOK DISCRETE STORMWATER DATA
STORM OF 29 JULY 1981

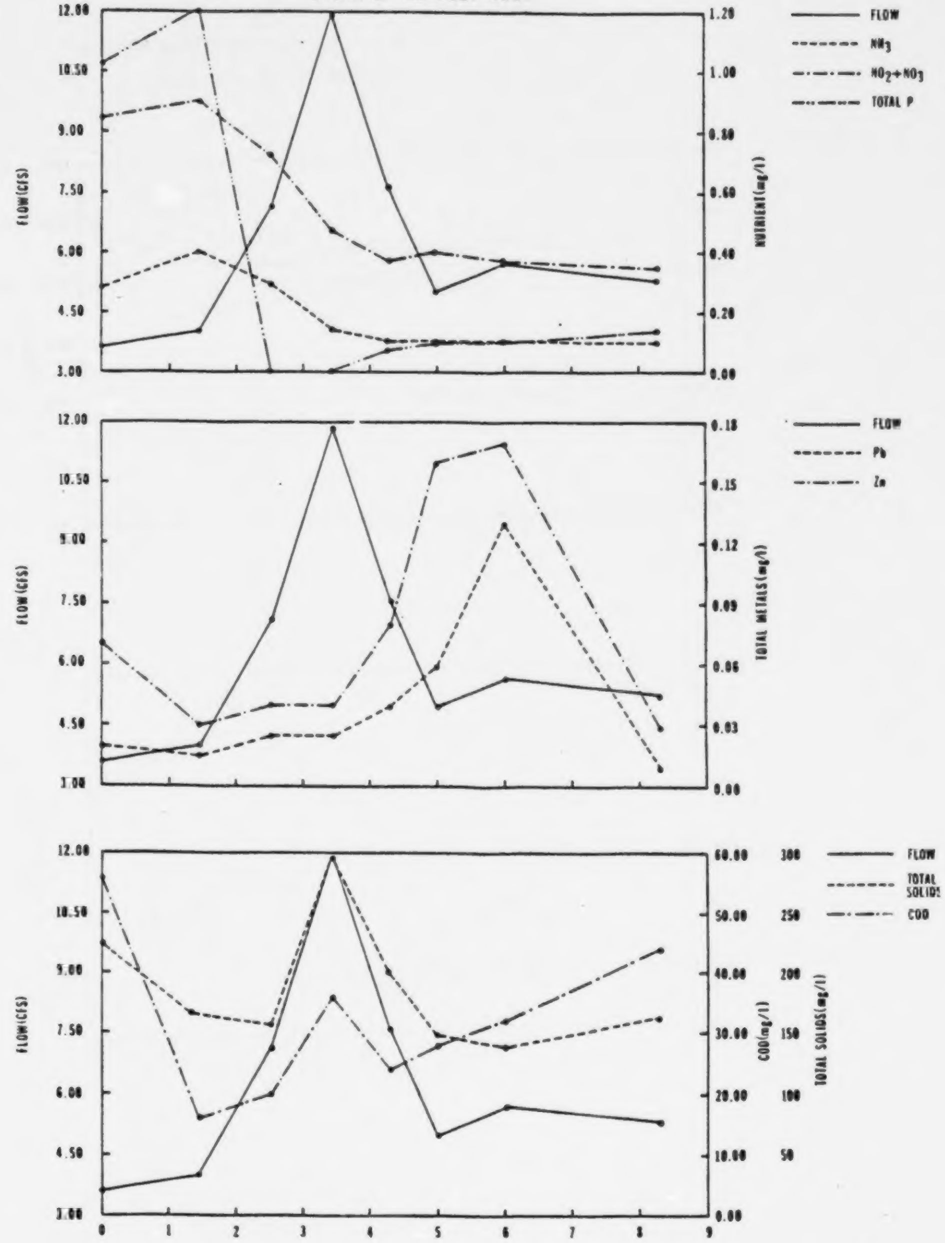
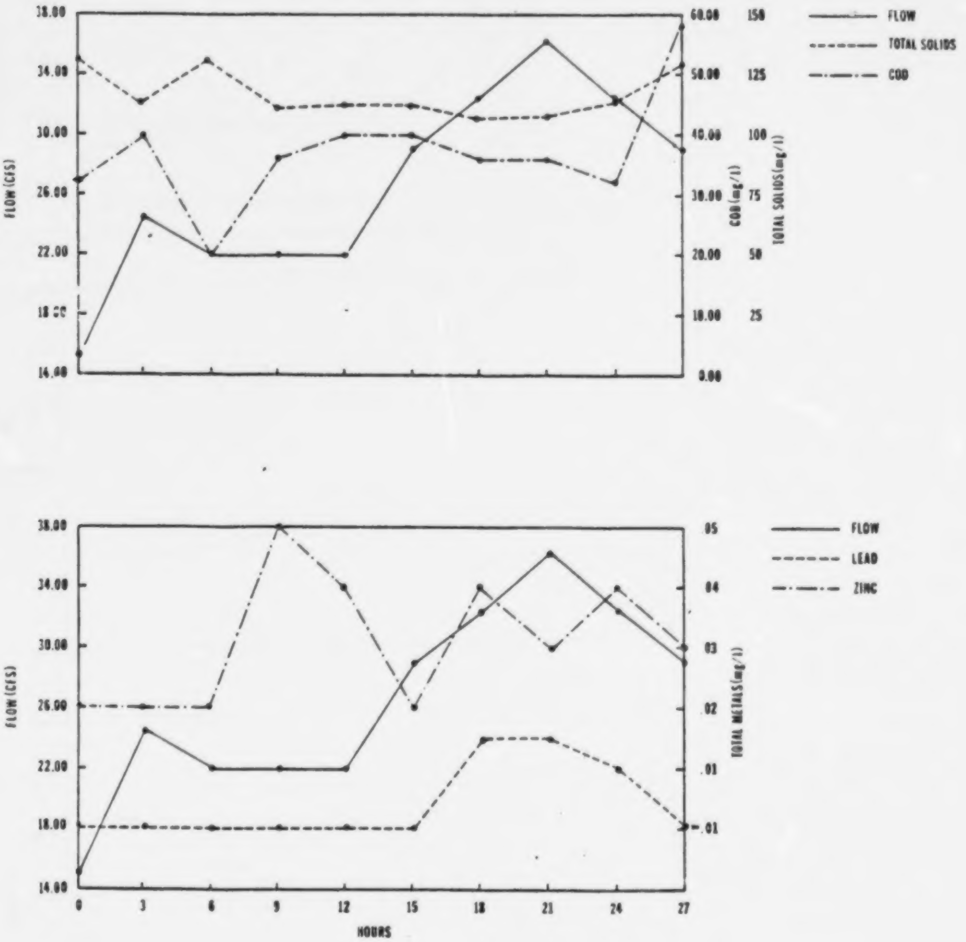


FIGURE 15
OYSTER RIVER DISCRETE STORMWATER DATA
STORM OF 29 JULY 1981



Summary

Dry weather and storm runoff water quality data have been analyzed with respect to New Hampshire Water Quality Standards and EPA criteria for toxic metals. Results show greater frequency of violations at downstream compared with upstream stations. Also, violations are more frequent during storm runoff when compared with dry weather periods.

Results for coliform bacteria reveal frequent violations at all stations during both wet and dry periods; however, dramatic stormwater runoff increases are indicated. Turbidity samples were collected during storm runoff periods only. Results show routine violations at both Pettee Brook stations, and less frequent violations in the Oyster River. Only minor differences between upstream and downstream stations are indicated.

Overall, metals concentrations were quite low in both the Oyster River and Pettee Brook. Although marked increases in stormwater over base flow concentrations were observed, concentrations high enough to result in toxic effects were rarely encountered. Results for parking lot runoff show frequent heavy metals violations, with concentrations of Zn and Cu reaching potentially toxic levels. Observed criteria violations coupled with the results of a time frequency of violation recurrence analyses for heavy metals suggest stormwater Zn and Cu concentrations could reach in-stream toxic levels on an infrequent basis.

Stormwater Runoff Mass Loads

Stormwater quality and quantity data for each study catchment have been used to calculate mass loads for many constituents analyzed. Mass load expressions are useful in comparing water quality constituent yields among different land use types. Once defined, mass load data become particularly valuable in predicting pollutant loads as a result of urban development.

To enable comparison of stormwater runoff pollution yield among catchments and with reported literature values, mass loads have been expressed in several terms as presented in Appendix II. For ease of discussion, focus here is restricted to the expression "lbs./acre/year."

Pettee Brook

Gross stormwater quality and quantity measurements collected in this study include both base flow conditions and stormwater runoff perturbations. Although gross stormwater loads are comparable among catchments, net storm-generated loads (base flow loads removed) better represent the pollutant contributions of specific land uses. To enable the calculation of net stormwater mass loads, base flow mass loads determined from the dry weather data base have been removed. Results of these calculations appear in Table 35.

For all water quality constituents except NH_3 and total volatile solids in the 3-Pte catchment, and Cr in the 2-Pte catchment, a net quantitative mass load increase results from stormwater runoff. Note the increased mass loads as determined at the downstream (2-Pte) station in comparison to the upstream (3-Pte) background station. These increases can be attributed to increased urbanization in the 2-Pte catchment.

TABLE 35
PETTEE BROOK MASS LOADS
Lbs./Acre/Year

Constituent	UPSTREAM (3-Pte) Gross Stormwater Load	UPSTREAM (3-Pte) Base Flow Component Load*	UPSTREAM (3-Pte) Net Stormwater Load	DOWNSTREAM (2-Pte) Gross Stormwater Load	DOWNSTREAM (2-Pte) Base Flow Component Load*	DOWNSTREAM (2-Pte) Net Stormwater Load
BOD	6.3409	0.9225	5.4184	19.5638	0.7970	18.7668
COD	30.8172	16.7166	14.1006	72.7894	16.4703	56.3191
TKIV	3.0203	0.4018	2.6185	1.8781	0.3640	1.5141
NH_3	0.0777	0.0873	0	0.1173	0.0511	0.0662
NO_2 + NO_3	0.3643	0.1600	0.2043	0.4937	0.1281	0.3656
PO_4	0.0160	0.0031	0.0129	0.0196	0.0018	0.0178
P	0.1657	0.0431	0.1226	0.1535	0.0182	0.1353
Cd	0.0198	0.0028	0.0170	0.0083	0.0026	0.0057
Cr	0.0202	0.0065	0.0137	0.0268	0.0940	0
Cu	0.0657	0.0516	0.0141	0.1071	0.0518	0.0553
Fe	5.6853	0.5254	5.1599	8.8972	0.4129	8.4843
Pb	0.0389	0.0056	0.0333	0.1198	0.0054	0.1144
Mg	2.7101	1.7462	0.9639	3.9413	1.7673	2.1740
Mn	0.2160	0.1278	0.0882	0.6034	0.0653	0.5381
K	2.0934	1.9098	0.1836	3.5881	1.8765	1.7116
Na	10.3231	9.1458	1.1773	36.4085	9.9546	26.4539
Zn	0.0718	0.0081	0.0637	0.1391	0.0091	0.1300
Tot. Solids	199.7851	92.2760	107.5091	312.5366	81.1918	231.3448
Susp. Solids	109.1630	3.9127	105.2503	226.1213	3.0158	223.1055
Tot. Vol. Solids	39.4386	123.8382	0	83.2309	-	-
Susp. Vol. Solids	7.6708	-	-	51.0295	2.3095	48.7200

CATCHMENT CHARACTERISTICS

Urban Land Use	10%	23%
Impervious Cover	1%	4.8%
Persons/Acre	0.2%	3.8%

*Base flow component calculated as: Mean base flow load (Lbs./day)
*Average stormwater runoff duration/storm
*83 storms/year (0.1" precip. or more)

Oyster River

Table 36 presents a similar mass load summary for the two Oyster River catchments. Note that significant stormwater loads are generated for all water quality constituents measured. Results for the Oyster River also show a net increase in stormwater loads between the upstream and downstream catchments. As with the Pettee Brook summary, several pertinent land use characteristics appear in Table 36. Based upon these characteristics alone, one would expect greater loads from the upstream Pettee Brook catchment compared to upstream Oyster River. However, the data show otherwise, suggesting other catchment characteristics, in addition to those presented in Table 1, control mass load rates in rural catchment areas.

Parking Lot

Stormwater runoff mass loading rates for the parking lot catchment are presented in Table 37. As expected, loading rates at this site are the highest observed in the study area. These results reflect rather dramatically the impact of urbanization on stormwater runoff loads.

Table 37 also presents net urban catchment loads for both Pettee Brook and the Oyster River. Overall, stormwater loads from the Oyster River catchment are shown to be less than Pettee Brook loads, presented in terms of lbs./acre/yr. However, it is suspected that these loads may not reflect the entire contribution of urban drainage to the Oyster River, since settling of suspended materials is suspected in the impoundment just upstream of 5-Oys (Mill Pond).

TABLE 36
OYSTER RIVER MASS LOADS
LBS./ACRE/YEAR

	UPSTREAM (7-Oys)			DOWNSTREAM (5-Oys)		
Constituent	Gross Stormwater Load	Base Flow Component Load*	Net Stormwater Load	Gross Stormwater Load	Base Flow Component Load*	Net Stormwater Load
BOD	6.2611	0.9939	6.1617	16.5090	2.3390	14.1700
COD	30.6321	21.3177	28.5002	91.0892	46.6609	44.4283
TKIV	0.6820	0.4073	0.6413	1.9088	0.9441	0.9647
NH_3	0.1745	0.0723	0.1672	0.2965	0.1400	0.1565
$NO_2 + NO_3$	0.3909	0.1448	0.3764	0.7177	0.2512	0.4665
PO_4	0.0121	0.0024	0.0118	0.0390	0.0047	0.0343
P	0.0640	0.0306	0.0653	0.1733	0.0570	0.1163
Cd	0.0054	0.0040	0.0049	0.0190	0.0084	0.0106
Cr	0.0242	0.0089	0.0233	0.0519	0.0191	0.0328
Cu	0.0917	0.0792	0.0837	0.2266	0.1658	0.0608
Fe	0.8630	0.4212	0.8138	2.5739	1.0860	0.4871
Pb	0.0095	0.0081	0.0086	0.0321	0.0166	0.0155
Mg	2.2355	1.6195	2.0736	6.4422	3.7793	2.6629
Mn	0.0710	0.0476	0.0662	0.2026	0.0944	0.1082
K	3.6923	0.6014	3.6321	6.1725	1.9755	4.1970
Na	10.8372	15.4389	9.2932	34.1878	26.9048	7.2830
Zn	0.0943	0.0072	0.0935	0.1624	0.0300	0.1324
Tot. Solids	97.1960	70.4373	90.1522	287.788	144.1561	143.6319
Susp. Solids	3.68850	3.9171	3.2967	18.0818	3.3065	14.7753
Tot. Vol. Solids	36.9850	35.7779	33.4069	124.5045	71.8996	52.6049
Susp. Vol. Solids	1.4894	1.4670	1.3426	4.6235	1.8858	2.7377

CATCHMENT CHARACTERISTICS

Urban Land Use	1%	5.8%
Impervious Cover	1%	1.7%
Persons/Acre	0.03%	0.30

*Base flow component calculated as: Mean base flow load (Lbs./day)
*Average stormwater runoff duration/storm
*83 storms/year (0.1" precip. or more)

Mass Loading Data Summary

For instream study catchments, the sampling strategy used to assess impacts of urbanization was based upon the quantitative determination of net stormwater and associated contaminant input between upstream reference stations (3-Pte and 7-Oys) and downstream test stations (2-Pte and 5-Oys). The result produced is an estimation of the stormwater runoff mass loading rates which are attributed to the specific land use and physical catchment characteristics between stations.

Mass loading data for the catchment area between the two Pettee Brook stations reveal a net increase in all constituents except for TKN, Cd, and Cr. Although not quantifiable, stormwater quality in Pettee Brook is influened by filter backwashing effluent from the University swimming pool, as discussed earlier. The loss of TKN between stations is likely the result of instream nitrification of urea. Results for Cd and Cr are more difficult to explain; however, the potential exists for both swimming pool and other nonpoint source inputs which are settled or lost to other "sinks" in the stream channel.

Results for the Oyster River also reveal a net increase for most water quality constituents with NH_3, Cu, and Na increasing slightly. Generally, load increases were less than expected, suggesting the possible existence of a pollutant "sink." Analysis of sediment oxygen demand and sediment heavy metals suggests that the impoundment immediately above 5-Oys acts as a settling pond for suspended materials.

TABLE 37

Urban Catchment Mass Load Summaries

Lbs./Acre/Year[1]

Constituent	Parking Lot (1-Pkg) Load	Pettee Brook (2-Pte. less 3-Pte) Net Load	Oyster River (5-Oys less 7-Oys.) Net Load
BOD	99.9887	13.3484	8.0083
COD	476.3717	42.2185	15.9281
TKN	11.1864	-1.1044	0.3233
NH_3	3.5937	0.0758	-0.0108
NO_2+NO_3	4.4387	0.1613	0.0901
PO_4	0.2838	0.0049	0.0225
P	1.4580	0.0127	0.0510
Cd	0.0359	-0.0113	0.0056
Cr	0.1322	-0.0809	0.0095
Cu	0.6357	0.0412	-0.0023
Fe	9.8536	3.3244	0.6733
Pb	1.0966	0.0811	0.0068
Mg	6.0096	1.2101	0.5893
Mn	0.5369	0.4499	0.0420
K	10.5162	1.5280	0.5648
Na	17.7812	25.2766	-2.0103
Zn	2.7917	0.0663	0.0389
Tot. Solids	577.0360	123.8537	53.4797
Susp. Solids	333.2820	117.8552	11.4786
Tot. Vol. Solids	297.0627	-	19.1980
Susp. Vol. Solids	177.7596	-	1.3954

[1] - Based upon 42" annual precipitation

CATCHMENT CHARACTERISTICS

Urban Land Use	100%	100%	29%
Impervious Cover	100%	27%	5%
Persons/Acre	-	24.5	1.6

Not surprisingly, mass loading rates at the parking lot site are the highest observed in the study area. Unlike mass loading data for the other study sites, results obtained from the parking lot site are readily extrapolated to existing or planned paved parking lots in the State. Where sensitive receiving waters are a concern, the mass loading rate data developed here may prove to be a valuable aid in highlighting those areas where stormwater runoff treatment/diversion is necessary to restore or maintain water quality.

Parking Lot Priority Pollutant Analysis

Screening for priority pollutants as defined in Section 307(a)(i) of the 1977 Clean Water Act (33 U.S.C. 466 et. seq.; Committee Print HR. 3199), were performed on samples of initial runoff from the parking lot site collected 29 July 1981 and 25 August 1982. The results, as presented in Table 38, show no detectible concentrations in any of the organic compounds tested.

Also included in Table 38 are results of extensive metals testing of the 29 July 1981 sample. These analyses were performed by Versar Inc. under contract to USEPA. Analytical methods and procedures employed are presented in the report entitled, "NURP Priority Pollutant Monitoring Program. Volume III - Special Metals Sampling Data." USEPA, Monitoring and Data Support Division. September 17, 1982.

For metals classified as priority pollutants, detection limits for Cr, Cu, Pb, N and Zn, were exceeded. The concentrations encountered were within the range of concentrations presented in Section I.4 of this report which summarizes discrete water quality data for the parking lot site. Also included in table 38 are results for As, Be, Hg, Se, Ag, and Tl, which are classified as priority pollutants. Routine analysis at the Water Supply and Pollution Control Commission labs have not included these metals, therefore, it is particularly revealing to note that detection limits have not been exceeded in what is typically the most contaminated runoff (i.e., initial runoff) from the parking lot site.

TABLE 38
PARKING LOT
STORMS OF 29 JULY 1981 AND 25 AUGUST 1982
DISCRETE SAMPLE OF INITIAL RUNOFF
ORGANICS/PRIORITY POLLUTANTS ANALYSIS[a]

(All conc. in PPB)	29 July 1981 Replicates			25 August 1982
PESTICIDES	35074	35073	35072	
Acrolein	NT	NT	NT	NT
Aldrin	ND	ND	ND	NT
a-BHC (Alpha)	ND	ND	ND	NT
B-BHC (Beta)	ND	ND	ND	NT
Y-BHC (Lindane) (gamma)	ND	ND	ND	NT
d-BHC (Delta)	ND	ND	ND	NT
Chlordane	ND	ND	ND	NT
DDD	ND	ND	ND	NT
DDE	ND	ND	ND	NT
DDT	ND	ND	ND	NT
Dieldrin	ND	ND	ND	NT
a-Endosulfan (Alpha)	NT	NT	NT	NT
b-Endosulfan Sulfate (Beta)	NT	NT	NT	NT
Endosulfan sulfate	NT	NT	NT	NT
Endrin	ND	ND	ND	NT
Endrin aldehyde	ND	ND	ND	NT
Heptachlor	ND	ND	ND	NT
Heptachlor epoxide	NT	NT	NT	NT
Isophorone	NT	NT	NT	NT
TCDD	NT	NT	NT	NT
Toxaphene	ND	ND	ND	NT
PCB's				
PCB-1016 (Aroclor 1016)	NT	NT	NT	NT
PCB-1221 (Aroclor 1221)	NT	NT	NT	NT
PCB-1232 (Aroclor 1232)	NT	NT	NT	NT
PCB-1242 (Aroclor 1242)	NT	NT	NT	NT
PCB-1248 (Aroclor 1248)	NT	NT	NT	NT
PCB-1254 (Aroclor 1254)	NT	NT	NT	NT
PCB-1260 (Aroclor 1260)	NT	NT	NT	NT
2-Chloronaphthalene	ND	ND	ND	NT
HALOGENATED ALIPHATICS				
	35077	35076	35075	
Methane, bromo-	NT	NT	NT	ND
Methane, chloro-	NT	NT	NT	ND
Methane, dichloro-	NT	NT	NT	ND
Methane, chlorodibromo-	NT	NT	NT	ND
Methane, dichlorobromo-	NT	NT	NT	ND
Methane, tribromo-	NT	NT	NT	ND
Methane, trichloro-	NT	NT	NT	ND
Methane, tetrachloro-	NT	NT	NT	ND
Methane, trichlorofluoro-	NT	NT	NT	ND
Methane, dichlorodifluoro-	NT	NT	NT	ND

a. NT = Not tested; ND = None detected, detection limits presented in: 40 CFR. July 1982. Parts 136 and 136.3, Methods 624 and 625.

TABLE 38 (Continued)

PHTHALATE ESTERS				
Phthalate, bis (2-ethylhexyl)-	ND	ND	ND	ND
Phthalate, butyl benzyl-	ND	ND	ND	ND
PAH's				
Acenapthene				ND
Acenapthylene				ND
Anthracene				ND
Benzo (a) anthracene				ND
Benzo (b) fluoranthene				ND
Benzo (k) fluoranthene				ND
Benzo (ghi) perylene				ND
Benzo (a) pyrene				ND
Chrysene				ND
Dibenzo (a,H) anthracene				ND
Fluoranthene				ND
Fluroene				ND
Indeno (1,2,3-cd) pyrene				ND
Naphthalene				ND
Phenanthrene				ND
Pyrene				ND
N-Compounds	35092	35091	35090	
Nitrosamine, dimethyl- (DMN)	ND	ND	ND	NT
Nitrosamine, diphenyl-	ND	ND	ND	NT
Nitrosamine, di-n-propyl-	ND	ND	ND	ND
Benzidine	ND	ND	ND	ND
Benzidine, 3,3'-dichloro-	ND	ND	ND	ND
Hydrazine, 1,2-diphenyl-	ND	ND	ND	ND
Acrylonitrile	ND	ND	ND	ND

TABLE 38 (Continued)

HALOGENATED ALIPHATICS				
Ethane, chloro-	NT	NT	NT	ND
Ethane, 1,2-dichloro-	NT	NT	NT	ND
Ethane, 1,1,1-trichloro-	NT	NT	NT	ND
Ethane, 1,1,2-trichloro-	NT	NT	NT	ND
Ethane, 1,1,2,2-tetrachloro-	NT	NT	NT	ND
Ethane, hexachloro-	NT	NT	NT	ND
Ethene, chloro-(vinyl chloride)	NT	NT	NT	ND
Ethene, 1,1-dichloro-	NT	NT	NT	ND
Ethene, trans-dichloro-	NT	NT	NT	ND
Ethene, trichloro-	NT	NT	NT	ND
Ethene, tetrachloro-	NT	NT	NT	ND
Propane, 1,2-dichloro-	NT	NT	NT	ND
Propene, 1,3-dichloro-	NT	NT	NT	ND
Butadiene, hexachloro-	NT	NT	NT	NT
Cyclopentadiene, hexachloro-	NT	NT	NT	NT
ETHERS				
Ether, bis (choromethyl)	ND	ND	ND	ND
Ether, bis (2-chloroethyl)	ND	ND	ND	ND
Ether, bis (2-chloroisopropyl)	ND	ND	ND	ND
Ether, 2-chloroethyl vinyl	ND	ND	ND	ND
Ether, 4-bromophenyl pheryl	ND	ND	ND	ND
Bis (2-chloroethoxy) methane	ND	ND	ND	ND
MONOCYCLIC AROMATICS	35083	35082	35081	
Benzene	ND	ND	ND	ND
Benzene, chloro-	ND	ND	ND	ND
Benzene, 1,2-dichloro-	ND	ND	ND	NT
Benzene, 1,3-dichloro-	ND	ND	ND	NT
Benzene, 1,4-dichloro	ND	ND	ND	NT
Benzene, 1,2,4-trichloro-	ND	ND	ND	NT
Benzene, hexachloro-	ND	ND	ND	NT
Benzene, ethyl-	ND	ND	ND	NT
Benzene, nitro-	ND	ND	ND	NT
Toluene	ND	ND	ND	ND
Toluene, 2,4-dinitro-	ND	ND	ND	NT
Toluene, 2,6-dinitro	ND	ND	ND	NT
PHENOLS AND CRESOLS	35086	35085	35084	
Phenol	ND	ND	ND	ND
Phenol, 2-chloro-	ND	ND	ND	ND
Phenol, 2,4-dichloro-	ND	ND	ND	ND
Phenol, 2,4,6-trichloro-	ND	ND	ND	ND
Phenol, pentachloro-	ND	ND	ND	ND
Phenol, 2-nitro	ND	ND	ND	ND
Phenol, 2,4-dinitro-	ND	ND	ND	ND
m-Cresol, p-chloro	ND	ND	ND	ND
o-Cresol, 4,6-dinitro-	ND	ND	ND	ND
PHTHALATE ESTERS	35089	35088	35087	
Phthalate, dimethyl-	ND	ND	ND	ND
Phthalate, diethyl-	ND	ND	ND	ND
Phthalate, di-n-outyl-	ND	ND	ND	ND
Phthalate, di-n-octyl-	ND	ND	ND	ND

TABLE 38 (Continued)
Storm of 29 July 1981

Metals	Total	Total Recoverable	Dissolved
AL	1.700	1.600	1.400
As	0.010	0.010	0.010
Ba	0.040	0.040	0.040
Be	0.002	0.002	0.002
B	0.950	0.200	0.070
Cd	0.005	0.005	0.005
Ca	17.000	17.200	18.400
Cr	0.020	0.010	0.010
Co	0.010	0.010	0.010
Cu	0.100	0.100	0.100
Fe	1.780	1.700	1.240
Pb	0.520	0.520	0.440
Li	0.010	0.010	0.010
Mg	2.600	2.600	2.700
Mn	0.200	0.190	0.200
Hg	0.001	-	0.001
Mo	0.010	0.010	0.010
Ni	0.060	0.060	0.060
K	4.000	4.000	4.000
Se	0.010	0.010	0.010
Ag	0.010	0.010	0.010
Na	17.000	17.300	18.100
Sr	0.070	0.070	0.080
Tl	0.010	0.010	0.010
Sn	0.050	0.050	0.010
Ti	0.040	0.030	0.030
V	0.030	0.030	0.030
Y	0.010	0.010	0.010
Zn	2.080	2.160	2.340

SECTION II

PHASE II

CONTROL EVALUATIONS

II.1 CONTROL FEASIBILITY/SELECTION

Consistent with overall objectives, Phase II of the study was intended to evaluate specific urban runoff control measures. Phase I data analyses have provided the basis for a determination of control evaluation feasibility, and control device selection. A total of three control methods have been evaluated, two at the Parking lot site, and another in the Oyster River catchment. Below is a summary of factors considered in each catchment.

PARKING LOT SITE

Water quality data collected in Phase I reveal routinely poor stormwater runoff quality produced from this 0.8 acre paved area. New Hampshire water quality standards for coliform bacteria and turbidity, and EPA criteria for lead, zinc, copper, and cadmium, are violated with regular frequency at this site.

Typical control measures associated with urban parking lots and other street surfaces have involved source control such as street sweeping to reduce the mass of pollutants in the washoff, and diversion of the runoff into detention/sedimentation areas which reduce runoff volumes and stormwater-borne pollutants. The opportunity to evaluate both of these control types was presented at the Durham parking lot site.

Grassed Swale

Vegetated waterways (swales) are among the most widely used stormwater control structures in New Hampshire. In fact, this control type is being required under State Statute RSA 149:8-a for new developments which "...significantly alter the characteristic of the terrain, in such a manner as to impede the natural runoff or create an unnatural runoff..."

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Vegetated swale performance data generated in this evaluation was intended as an aid to engineers in selecting appropriate applications for grassed swale systems.

The stormwater quality and flow data collection scheme utilized in Phase I involved the routing of runoff into a terminal sampling station downgradient of the parking lot. Stormwater discharged from the sampling station flowed through a low marshy area adjacent to a small receiving stream approximately 30 feet distant. This area was ideally suited for grassed swale evaluation since only minor grade modifications were required for installation, and the marshy area consisted of a nearly pure stand of reed canary grass, which is a preferred cover for vegetated swales typically designed by the Soil Conservation Service (USDA) for purposes of erosion control.

Parking Lot Vacuum Cleaning

The area contributing runoff to the 1-Pkg sampling site serves as a parking lot for a commercial supermarket. Early in the Phase 1 study period it was discovered that employees of the supermarket cleaned the parking lot each day, using a lawn mower type vacuum cleaner. In order to accurately characterize runoff quality prior to control implementation during Phase II, it was necessary to request that this practice be temporarily suspended. The store management was cooperative and agreed to suspend vacuuming for the duration of Phase I.

In addition to the obvious aesthetic benefits, reactivation of vacuum cleaning during Phase II provided a unique opportunity to evaluate the effectiveness of this practice in reducing stormwater runoff pollutant loads from the site.

OYSTER RIVER CATCHMENT

With the exception of coliform bacteria, stormwater sampling has revealed consistent Class B water quality discharged at 5-Oys into tidewater. Actually, data suggest fecal coliform concentrations in excess of 200 counts/100 ml will occur with a probability of nearly 80 percent in stormwater discharged at 5-Oys. This compares with a probability of nearly 45 percent upstream at the water supply reservoir.

Considering the widespread heavy stormwater fecal coliform concentrations generated in the 7-Oys catchment, which is 98 percent forested and less than 0.2 percent impervious, it seems unlikely that any control installed downstream in the 5-Oys catchment would be successful in achieving target coliform concentrations of less than 200 fecal. Even if significant reductions were possible, the potential for carryover of bacterial contamination discharged at 7-Oys may result in persistent poor water quality downstream at the 5-Oys site.

Data generated during Phase I show generally decreased stormwater runoff contaminant concentrations between upstream and downstream sampling locations (7- and 5-Oys). Since it is reasonable to expect an increase in constituent concentrations due to the more urbanized intervening drainage area between stations, it is probable that substantial settling of suspended materials occurs in the impoundment just upstream of 5-Oys (Mill Pond). In fact, comparison of sediment metals data collected in both Mill Pond and the water supply reservoir show routinely higher concentrations of chromium, zinc and lead in Mill Pond. Considering the greater acreage of drainage area contributing to the reservoir compared with Mill Pond (10,560 acres vs. 2,181), and the fact that ambient metal concentrations in river water discharged from the reservoir are routinely less than detection limits, considerable metal loadings are most likely generated as a result of urbanization in the 5-Oys catchment. Thus, it appears that Mill Pond is acting as a settling pond.

Mill Pond's function as a sediment trap does not significantly interfere with other desirable uses. Viable upstream spawning areas for river herring, including Alewives and Littlebacks, remain unaffected. Aesthetic qualities of the area excell, including urban-parkland around the Pond. However, the accumulation of suspended materials and associated nutrients has resulted in excessive aquatic plant growth in some areas of the pond which is occasionally removed by the town.

River-Run Impoundment

Apparently, this run-of-the-river settling pond represents a passive control for stormwater generated pollutants and, as such, has been evaluated in terms of pollutant removal efficiency. The sampling strategy designed to accomplish this evaluation required water quality and flow monitoring of tributary inputs to Mill Pond as well as the outlet. The data has enabled quantification of contaminant removal efficiencies in Mill Pond, through mass balance analysis.

PETTEE BROOK CATCHMENT

In late summer of 1980, it was discovered that the University swimming pool includes a filter backwash system which discharges to Pettee Brook immediately upstream of 3-Pte. (upstream Pettee Brook). Review of data collected throughout the study period suggests Pettee Brook data collected between 15 June and 30 August (1980 and 1981) are heavily influenced by filter backwash. Not only does this significantly reduce the Pettee Brook data base, but most of the critical summertime data are questionable in terms of defining urban runoff influences. The inability to characterize stormwater runoff influence in Pettee Brook during study Phase I has precluded control evaluations in the subcatchment.

II.2 GRASSED SWALE CONTROL EVALUATION

INTRODUCTION

The use of vegetated waterways for erosion control and sediment filtration, particularly in association with agricultural land stabilization, is well documented (Fogg, 1980). Municipal wastewater renovation with rooted aquatic plant waterways has also been reported (Pope, 1981; Jenkins, et al, 1981 (a) and (b)]. This technology has recently been applied to urban stormwater treatment. Typical applications involve an integrated treatment scheme of runoff conveyance and detention in grassed surface depressions, with subsequent groundwater infiltration (Lynard, et al, 1980). Pollutant mass removal efficiency of 99% for BOD_5, N, P, and TSS has been reported for this type of treatment (Wanielista, 1982), where 80% of the runoff volume is removed through groundwater infiltration. Recognizing the inherent ability of vegetated waterways to remove waterborne pollutants by filtration, absorption, adsorption, and volatilization, this study addresses pollutant removal efficiency where groundwater infiltration was not the intended sink for pollutant mass removal.

Swale Construction

The swale was designed following guidance presented by the United States Soil Conservation Service (1981) for a parabolic vegetated waterway (Figure 16). With dimensions of 10' top width by 1' bottom depth and slope of 1.5% over the 100' swale length, the design criteria were based upon the requirement to reduce runoff velocity through the structure to a maximum of 2 fps. The swale will produce the desired velocity reductions up to a peak runoff rate of 10 cfs, which would result from rainfall volumes expected to

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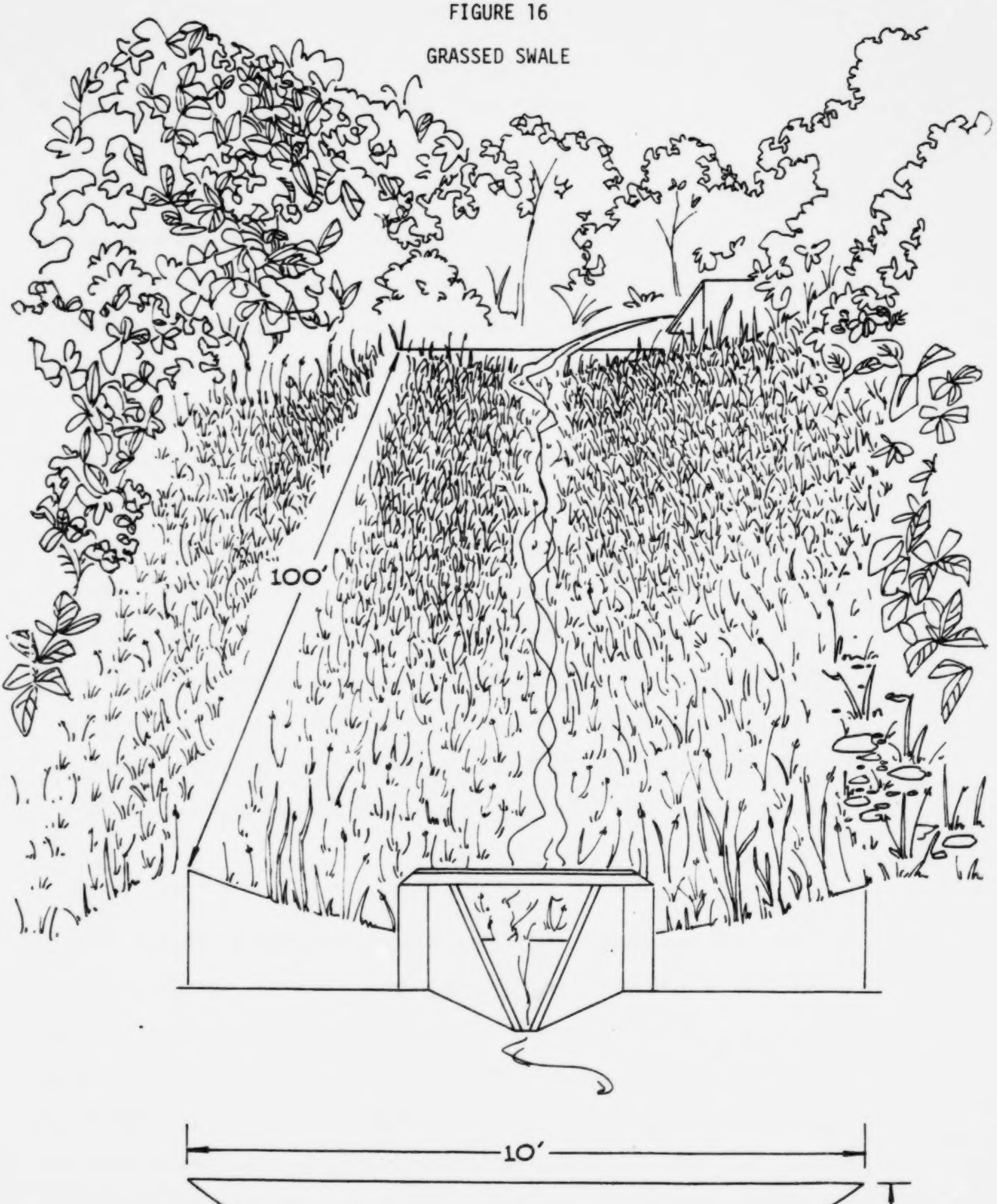
FIGURE 16

GRASSED SWALE



recur at 100 year intervals in the catchment area. The swale was intentionally overdesigned due to scale economy, and to allow for potential expansion of parking lot runoff area contributing to the structure.

The site selected for the swale installation was naturally vegetated with a nearly pure standing crop of reed-canary grass (*Phalaris arundinacea*), which is a recommended vegetative cover type for erosion control in grassed waterways (Soil Conservation Service, 1981). The soil was of a silty clay loam texture with very low permeability. Approximately 96 yards of fill were required to elevate the structure, thereby enabling flow measurements at the discharge location from the swale. Consistent with the study objective to evaluate stormwater-borne pollutant removal without groundwater infiltration, clay of silty loam texture was used as the fill material. Since site modifications were necessary and rapid stabilization of the structure was desired, the top 6" to 8" of soil and root-mat was stripped back with a DC-3 bulldozer and later replaced after the site modifications were completed.

Construction activities were performed during the period May 19 to 21, 1982. A stabilization period of 22 days followed, during which time the grass had grown to a height of approximately 12".

Instrumentation and Sampling Procedures

Three sampling stations were located over the length of the 100' structure. At the head and tail ends, continuous discharge monitoring was accomplished with H-flumes used in combination with ISCO Model 1870 flow meters. Discharge was not monitored at the third station, located midway (50') in the swale.

Water quality samples were collected with ISCO Model 1670 sequential discrete samplers. When used in combination with the flow meters, the sample collection frequency was paced according to predefined flow volume increments. This arrangement permitted both discrete analysis of water quality during the runoff period and flow weighted composite sampling of the entire event. The programming versatility of these instruments allowed for sampling of the "first flush" of contaminants from the catchment. Pacing of sample collection frequencies was synchronized at the head and tail end monitoring locations. Water quality sampling at the 50' station was effected with an ISCO Model 1640 Liquid Level Actuator which triggered a time-basis sample collection frequency. Flow-weighted composite sample preparation involved matching the time of sample collection with relative flow rate determined from the storm hydrograph recorded at the head end of the swale. The 50' station was activated late in the study period. As a consequence, limited data are available from this site.

Samples were collected as soon as possible after the runoff event, usually within 24 hours. Since the samples were collected as discrete grabs throughout the runoff, on-site determinations of pH and specific conductance were possible for each sample, thus providing an indication of variability in runoff quality during the event. In addition, aliquots of the composite sample, samples corresponding to the lowest pH encountered, and the initial runoff were filtered on-site and preserved for determination of dissolved metal fractions. Aliquots were also prepared for nutrients, solids, bacteria, physical-mineral, and oxygen demand analysis of the composite sample.

TABLE 39
VEGETATED SWALE DATA SUMMARY[a]
RUNOFF COMPOSITE SAMPLES
0' - Sw1

Parameter[b]	Number	Mean	Standard Deviation	Variance	Maximum	Minimum
Tot. Coli	8	465.125	137.698	18960.0	704.000	297.000
Fec. Coli	8	192.125	48.197	2322.98	267.000	148.000
Fec. Strep	8	168.875	31.868	1015.55	236.000	148.000
BOD	9	5.867	2.199	4.835	8.700	2.500
COD	11	76.909	45.083	2032.49	168.000	16.000
TKN	8	1.006	0.475	0.266	1.740	0.460
NH_3	10	0.235	0.172	0.030	0.560	0.100
NO_2+NO_3	11	0.761	0.453	0.205	1.430	0.220
PO_4	8	0.017	0.009	0.000	0.030	0.001
P	11	0.152	0.070	0.005	0.274	0.042
Cd, total	11	0.003	0.007	0.000	0.006	0.001
Cd, diss	8	0.002	0.002	0.000	0.008	0.001
Cr, total	11	0.030	0.000	0.000	0.030	0.030
Cr, diss	9	0.031	0.000	0.000	0.040	0.030
Cu, total	11	0.064	0.029	0.001	0.110	0.030
Cu, diss	9	0.057	0.026	0.001	0.100	0.030
Pb, total	11	0.122	0.056	0.003	0.200	0.025
Pb, diss	9	0.062	0.041	0.002	0.140	0.025
Sn, total	6	0.017	0.005	0.000	0.020	0.010
Sn, diss	5	0.016	0.005	0.000	0.020	0.010
Zn, total	11	0.339	0.236	0.056	0.800	0.090
Zn, diss	8	0.279	0.212	0.045	0.760	0.060
Cl	11	2.7	1.104	1.218	5.000	2.000
Hardness	11	55.0	64.3	4134.7	220.000	4.000
pH	11	4.148	1.010	1.020	4.95	3.58
Spec. Cond.	10	46.8	27.0	729.1	95.0	19.2
Turbidity	11	30.536	33.237	1104.7	120.0	4.6
Solids, total	10	116.7	78.2	6119.6	242.0	12.0
Solids, Sus	10	23.9	36.1	301.9	115.0	1.0

a. Concentration less than detection limits are reported as actual.

b. Coliform reported in units of 100 x $\log_{10}$ (MPN/100 ml), all others are mg/l except pH (std.units) and spec. cond. (µMHOs).

TABLE 40
VEGETATED SWALE DATA SUMMARY
RUNOFF COMPOSITE SAMPLES
100' - Swl

Parameter	Number	Mean	Standard Deviation	Variance	Maximum	Minimum
Tot. Coli	8	481.250	51.333	2635.1	559.000	418.000
Fec. Coli	8	266.375	93.436	8730.0	363.000	130.000
Fec. Strep	8	294.375	45.154	2038.8	361.000	236.000
BOD	8	4.850	2.037	4.149	8.800	2.000
COD	11	50.273	42.556	1811.018	152.000	10.000
TKN	9	0.730	0.253	0.064	1.120	0.350
NH_3	10	0.124	0.060	0.004	0.290	0.100
NO_2+NO_3	11	0.441	0.284	0.080	0.990	0.120
PO_4	8	0.025	0.026	0.001	0.084	0.001
P	11	0.124	0.055	0.003	0.260	0.069
Cd, total	11	0.002	0.001	0.000	0.004	0.001
Cd, diss	8	0.002	0.001	0.000	0.004	0.001
Cr, total	11	0.030	0.000	0.000	0.030	0.030
Cr, diss	9	0.030	0.000	0.000	0.030	0.030
Cu, total	11	0.037	0.021	0.000	0.100	0.030
Cu, diss	9	0.037	0.024	0.001	0.100	0.020
Pb, total	11	0.036	0.026	0.001	0.080	0.010
Pb, diss	9	0.017	0.016	0.000	0.060	0.010
Sn, total	6	0.017	0.005	0.000	0.020	0.010
Sn, diss	5	0.016	0.005	0.000	0.020	0.010
Zn, total	11	0.139	0.049	0.002	0.240	0.090
Zn, diss	7	0.131	0.034	0.001	0.180	0.090
Cl	11	3.8	4.167	17.364	16.000	2.000
Hardness	11	60.0	57.4	3292.8	200.000	4.000
pH	11	5.68	1.093	1.195	6.60	4.95
Spec. Cond.	11	44.5	34.6	1196.0	126.000	19.000
Turbidity	11	20.855	27.085	733.571	100.000	1.700
Solids, total	9	67.2	43.130	1860.2	127.000	13.000
Solids, Sus	10	15.8	25.832	667.3	88.000	1.000

TABLE 41

VEGETATED SWALE DATA SUMMARY
RUNOFF DISCRETE SAMPLES
0' - Swl

Parameter	Number	Mean	Standard Deviation	Variance	Maximum	Minimum
pH	9	4.00	1.124	1.263	4.80	3.50
Spec. Cond.	9	117.3	72.794	5299.0	285.000	45.000
Cd, total	9	0.006	0.003	0.000	0.012	0.002
Cd, diss	9	0.005	0.003	0.000	0.010	0.001
Cr, total	9	0.032	0.004	0.000	0.040	0.030
Cr, diss	9	0.030	0.000	0.000	0.030	0.030
Cu, total	9	0.134	0.077	0.006	0.300	0.070
Cu, diss	9	0.106	0.062	0.004	0.240	0.030
Pb, total	9	0.266	0.201	0.040	0.750	0.020
Pb, diss	9	0.207	0.138	0.019	0.500	0.040
Zn, total	9	1.649	2.109	4.448	7.000	0.260
Zn, diss	9	1.554	2.118	4.487	7.000	0.160

TABLE 42

VEGETATED SWALE DATA SUMMARY
RUNOFF DISCRETE SAMPLES
50' - Swl

Parameter	Number	Mean	Standard Deviation	Variance	Maximum	Minimum
pH	7	4.45	1.1006	1.211	4.80	3.80
Spec. Cond.	7	45.857	35.254	1242.810	120.000	10.000
Cd, total	7	0.004	0.003	0.000	0.009	0.001
Cd, diss	7	0.005	0.003	0.000	0.011	0.002
Cr, total	7	0.031	0.004	0.000	0.040	0.030
Cr, diss	7	0.030	0.000	0.000	0.030	0.030
Cu, total	7	0.054	0.033	0.001	0.100	0.030
Cu, diss	7	0.056	0.032	0.001	0.100	0.030
Pb, total	7	0.052	0.049	0.002	0.155	0.015
Pb, diss	7	0.033	0.030	0.001	0.085	0.010
Zn, total	7	0.486	0.387	0.150	1.100	0.140
Zn, diss	7	0.370	0.268	0.072	0.930	0.160

TABLE 43

VEGETATED SWALE DATA SUMMARY
RUNOFF DISCRETE SAMPLES
100' - Swl

Parameter	Number	Mean	Standard Deviation	Variance	Maximum	Minimum
pH	9	5.30	1.132	1.121	6.51	4.40
Spec. Cond.	9	54.111	30.399	924.111	110.000	20.000
Cd, total	9	0.003	0.002	0.000	0.007	0.001
Cd, diss	9	0.002	0.002	0.000	0.006	0.001
Cr, total	9	0.030	0.000	0.000	0.030	0.030
Cr, diss	9	0.030	0.000	0.000	0.030	0.030
Cu, total	9	0.054	0.029	0.001	0.100	0.030
Cu, diss	9	0.051	0.029	0.001	0.100	0.030
Pb, total	9	0.057	0.049	0.002	0.175	0.010
Pb, diss	9	0.037	0.038	0.001	0.135	0.010
Zn, total	9	0.240	0.120	0.014	0.410	0.060
Zn, diss	9	0.288	0.182	0.033	0.680	0.110

Results and Discussion

Stormwater-borne contaminant removal performance has been evaluated in terms of runoff event mean concentration changes at each swale station via flow-weighted composite sampling, and performance variability during the runoff event via discrete water quality sampling.

Stormwater Flow-Weighted Composite Samples

Storm event mean concentration changes between the head (0'-SWL) and tail ends (100'-SWL) of the swale are summarized in Table 44. Seventeen constituents show an overall removal over the 100 foot swale length. Twelve are significant at the $\alpha<.05$ level. More specifically, COD, total residue, NH_3, $NO_2 + NO_3$, and both total and dissolved fractions of Cd, Cu, Pb, and Zn concentrations were significantly reduced as a result of grassed swale treatment. Increases in pH were also significant, averaging 1.42 units.

Swale treatment did not result in significant removal of BOD, turbidity, specific conductance, org-N, or total P. Overall concentration increases were observed for suspended residue, PO_4, total and fecal coliforms and fecal streptococci bacteria.

Results for swale treatment of oxygen demanding materials suggest only marginal removal efficiency. Overall, BOD removal was only 11%, and although COD removal was significant, only 25% was removed overall.

Total residue removal, averaging only 33%, was significant. Results obtained for suspended residue indicate that the dissolved solids fractions were being removed while suspended fractions were not. This result was unexpected, and may be due to scouring of soil from the swale bottom, since the structure may not have been completely stabilized before use. Turbidity results also reflect poor suspended solids removal.

Table 44 Grassed Swale Treatment Results (11 Storms)

	Storm Water Runoff Composite Concentrations[a]				Overall Removal	Significance[b] Level
	0'-SWL		100'-SWL			
	Mean	Range	Mean	Range	%	$\alpha \leq .05$
BOD	5.9	2.5-8.7	4.9	2.0-8.8	11	-
COD	76.9	16.0-168.0	50.3	10.0-152.0	25	.034
Residue, Total	117	12-242	67	13-127	33	.011
Residue, Susp.	24	1-115	16	1-88	-	-
Turbidity, NTU	30.5	4.6-120.0	20.9	17.0-100.0	4	-
Spec. Cond., μMHOs	46.8	19.2-95.0	44.5	19.0-126.0	1	-
pH (increase)	4.02	3.58-4.95	5.44	4.95-6.60	1.42 units	.000
Org-N	0.76	0.36-1.28	0.60	0.25-0.98	16	-
NH_3	0.24	<0.10-0.56	0.12	<0.10-0.29	51	.008
NO_2+NO_3	0.76	0.22-1.43	0.44	0.12-0.99	32	.006
PO_4	0.017	<0.001-0.030	0.025	<0.001-0.084	-	-
P	0.152	0.042-0.274	0.124	0.069-0.260	5	-
Cd, Total	0.003	<0.001-0.006	0.002	<0.001-0.004	56	.015
Cd, Diss.	0.002	<0.001-0.006	0.002	<0.001-0.004	42	.046
Cu, Total	0.06	<0.03-0.11	0.04	<0.03-0.10	48	.002
Cu, Diss.	0.06	<0.03-0.10	0.04	0.02-0.10	53	.006
Pb, Total	0.122	0.025-0.200	0.036	<0.010-0.080	65	.000
Pb, Diss.	0.062	0.025-0.140	0.017	<0.010-0.060	63	.010
Zn, Total	0.34	0.09-0.80	0.14	0.09-0.24	51	.006
Zn, Diss.	0.28	0.06-0.76	0.13	0.09-0.18	47	.036
Total Coli., MPN	4.45×10^4	$930-11.00 \times 10^6$	6,490	$15,000-3.90 \times 10^5$	-	-
Fecal Coli., MPN	83	<30-460	461	<20-4,300	-	-
Fecal Strep.	49	<30-230	879	300-4,074	-	-

[a] Results mg/l unless indicated.

[b] Paired t-test, 1-tail prob.

Specific conductance showed basically no change resulting from swale treatment. In light of the dissolved solids results presented above, significant reduction in conductivity was expected.

Review of nutrient results suggest good nitrogen removal, but poor phosphorus removal efficiencies. Significant reductions in NH_3 (51%) and NO_2 + NO_3 (32%) were realized, perhaps due to plant uptake. Poor removal efficiency of org-N (16%) is indicated. Results for phosphorus suggest swale treatment is not an efficient means of removal. Total phosphorus removal averaged a meager 5%, and an overall increase in PO_4 was measured.

Bacteriological results show overall increases in contamination for each of the three groups tested; total coliform, fecal coliform, and fecal streptococci bacteria. These results suggest the possibility of animal wastes deposited in the structure.

Consistently significant removal of heavy metals is reflected in table 44. Overall removal ranged from 42% for dissolved cadmium to 65% for total lead. Although no attempt was made to determine the actual mechanisms involved in contaminant removal, it is probable that the rather dramatic increases in pH through the swale (averaging 1.42 units) may be an important factor. Swale mediated pH increases become even more interesting when viewed in consideration of the acid precipitation problem which plagues this area of the United States. Rain pH ranged between 3.3 and 4.5 for 9 storm events sampled.

The relationship between acid rain and the mobilization of metals is obviated by the results presented in table 45. With the exception of Cd, which exhibited only minor concentration changes in runoff entering the swale, significant correlations exist between rain pH and dissolved and total metals concentrations in parking lot runoff. Although the ratio of

TABLE 45

Rain pH vs Parking Lot Runoff Metal Concentrations

	N	Range	Mean	Median	Rain pH Range	Rain pH Median	Spearman's Rank Correlation Metal Concentration vs Rain pH
Total Cu	7	.030-.110	.059	.060	3.35-4.18	3.47	$\alpha < .010$
Diss Cu	7	.030-.090	.053	.050	3.35-4.18	3.47	$\alpha < .010$
Diss/Tot Cu	6	.750-1.00	.900	.917	3.35-4.18	3.50	not significant
Total Pb	7	.065-.195	.135	.135	3.35-4.18	3.50	$\alpha < .100$
Diss Pb	7	.030-.140	.069	.050	3.35-4.18	3.50	$\alpha < .100$
Diss/Tot Pb	7	.280-.796	.511	.370	3.35-4.18	3.50	not significant
Total Zn	7	.170-.800	.329	.290	3.35-4.18	3.50	$\alpha < .025$
Diss Zn	6	.170-.760	.337	.275	3.35-4.18	3.47	$\alpha < .050$
Diss/Tot Zn	6	.895-1.00	.963	.975	3.35-4.18	3.47	not significant

	N	Range	Median	Spearman's Rank Correlation Runoff pH vs Rain pH
Runoff pH	9	3.58-4.95	4.32	$\alpha < .005$
Rain pH	9	3.35-4.50	3.47	

dissolved to total metals is not shown to be significant, note that nearly all the Cu and Zn exist in dissolved form. It is assumed that at the very low rain pH values observed, only dissolved forms are possible, and the lack of significant correlations results from little or no variability in metal forms.

Heavy metal reductions via swale treatment are presented graphically in figure 17. Note that swale effluent concentrations of copper and zinc do not reach acute toxicity levels (NURP threshold and significant). Swale metals removal data have also been applied to the time frequency of criterion violation recurrence intervals discussed in Section I. Results of this analysis are presented in figure 18. As indicated, toxic concentrations are not expected within a reasonable time frame for any of the metals addressed.

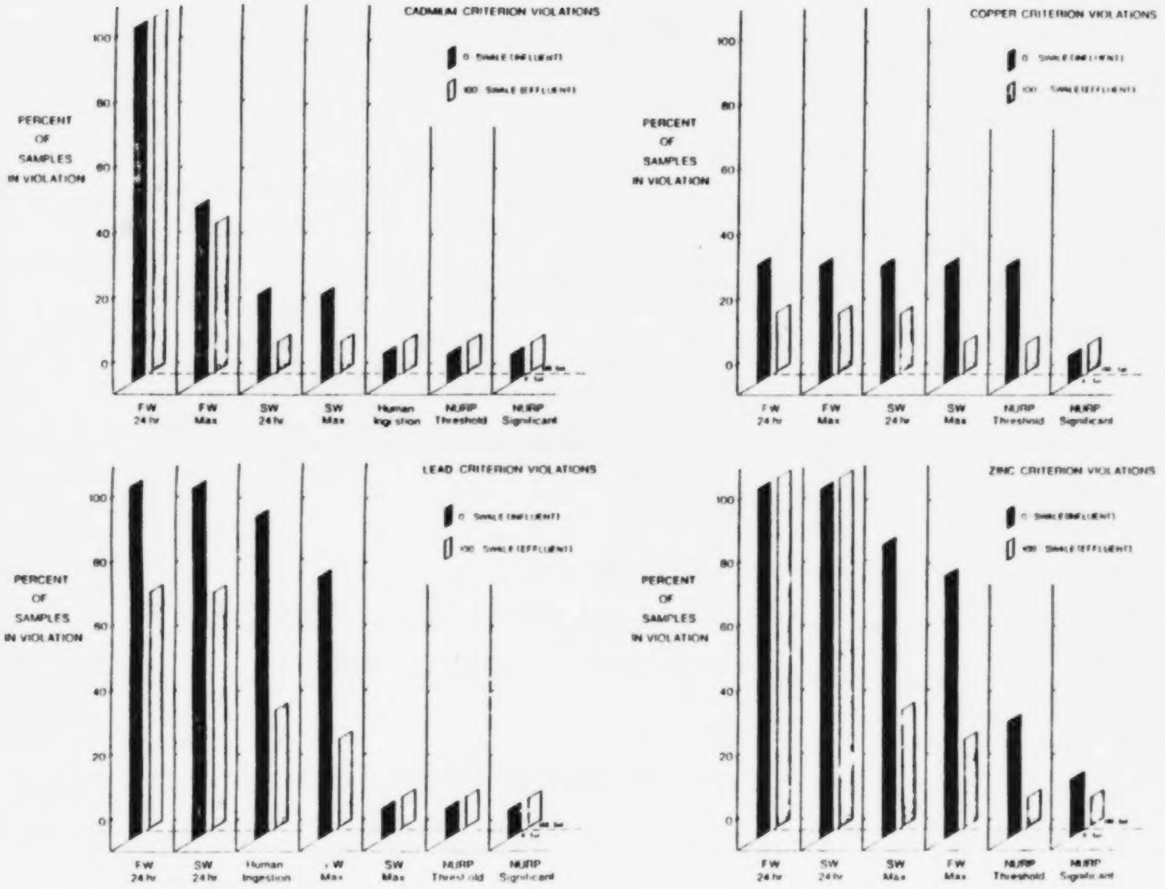
Stormwater Discrete Samples

Prior to preparation of flow weighted composite samples, on-site analyses of pH and specific conductance were performed on each discrete runoff sample collected during 7 storm events at 0'-swl and 100'-swl and 6 events at 50'-swl. These data provided an indication of water quality variability during runoff events at the 50'-swl location, thus enabling an estimation of water quality change with distance through the swale.

Sampling frequencies were synchronized at the 0'-swl and 100' swl locations on a runoff volume passage basis. Hence, samples collected at these locations for any given volume increment (i.e., 20 cf, 120 cf, 220 cf, etc.) are directly comparable. Sampling at the 50'-swl location was keyed to sampling at 100'-swl, therefore, these samples are not directly comparable to the other stations by volume increments. However, in reviewing storm hydrographs at the 0'-swl and 100'-swl locations, an

FIGURE 17

VEGETATED SWALE INFLUENT VS. EFFLUENT METALS CRITERION VIOLATIONS



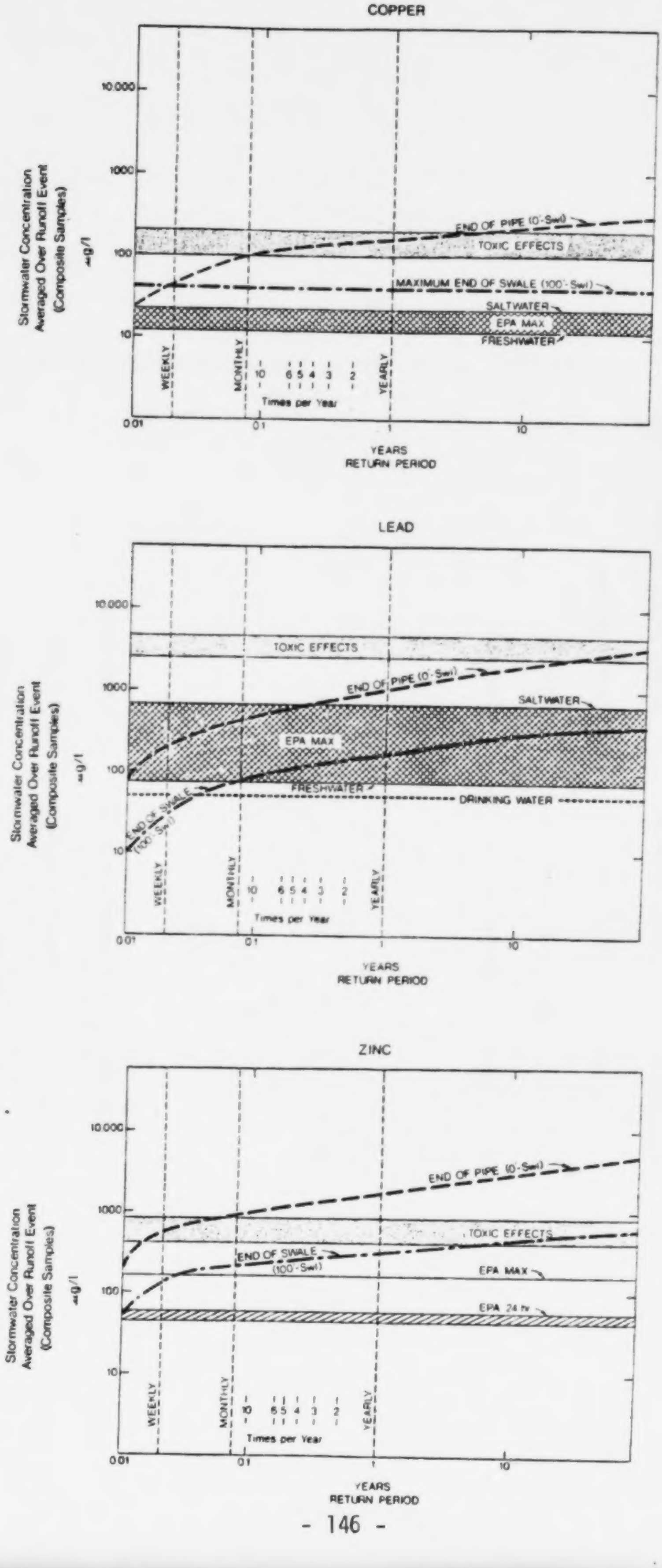


FIGURE 18
VEGETATED SWALE INFLUENT VS. EFFLUENT
RETURN PERIOD OF METALS CRITERION VIOLATIONS

approximate runoff velocity through the swale has been established. The velocities vary based upon flow rates as recorded at the 0-swl and 100'-swl locations. This relationship enabled graphical interpolation of 50'-swl water quality conditions at specific runoff volume increments which were then comparable to the 50'-swl and 100'-swl locations.

pH

Results for pH are presented in Table 46 and Figure 19. Although there appear tobe somewhat greater pH increases in the lower swale section (50'-swl to 100'-swl) for runoff volumes less than 500 cf, and greater pH increases in the upper swale section (0'-swl to 50' swl) for runoff volumes greater than 1100 cf, these increases are marginal at best, and with the exception of volume increments 320 and 420 cf, are not supported statistically. Since 50'-swl sampling was not activated until after passage of the "first flush" washoff from the parking lot, possible linear differences in swale treatment of the initial runoff cannot be evaluated.

Figure 19 is based upon only 2 datum at 50'-swl for volume increments 1100 through 1600 cf, therefore, no meaningful trend can be established. It is important to note that as few as 3 datum are sufficient to show significance of pH changes between the 0'-swl and 100'-swl locations.

On this basis, one can conclude that for runoff volumes greater than 120 cf, pH changes over the length of the swale structure are generally constant, with little discernible difference between the upper 50 feet and lower 50 feet of swale length. Given the relationship previously established between pH and heavy metals concentration, it is also probable that metals removal is generally constant over the entire swale length, with no significant changes in removal rate in the upper versus lower swale sections.

TABLE 46

GRASSED SWALE
DISCRETE RUNOFF SAMPLES
SIGNIFICANCE OF pH CHANGE[a]

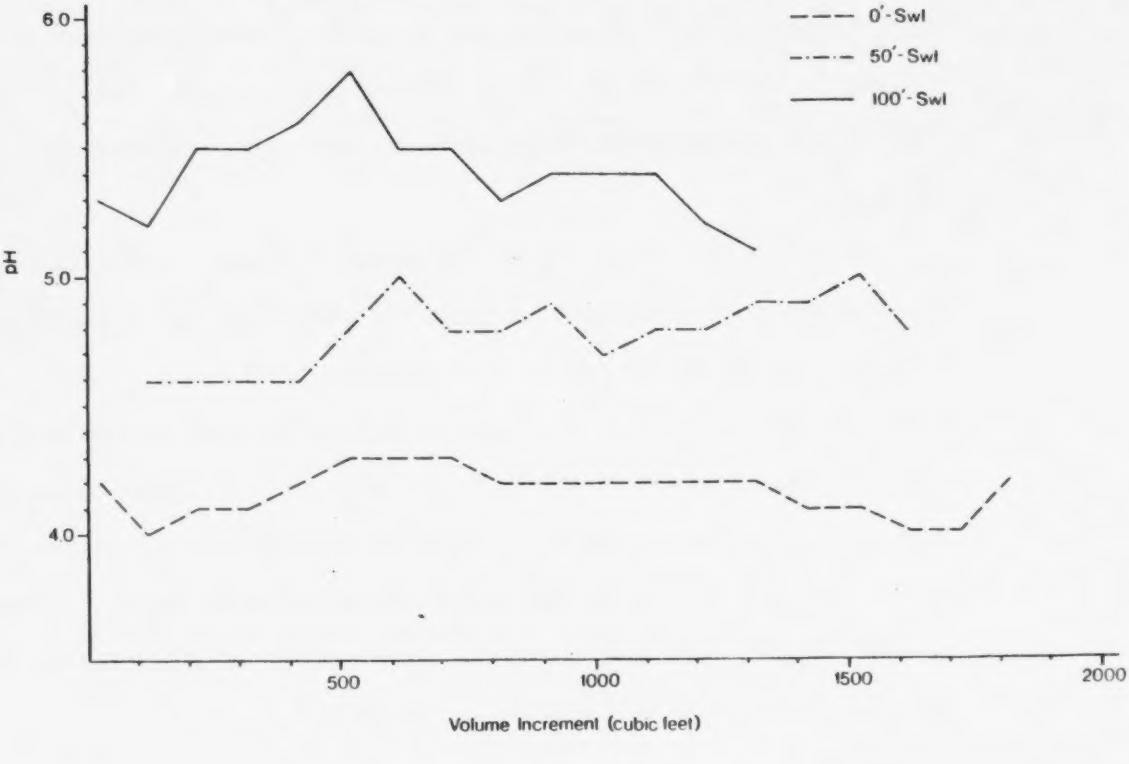
Volume Increment (cubic feet)	0'-swl to 50'-swl Units change	Vs.	50'-swl to 100'-swl Units change	α	0'-swl to 100'-swl Units change	α
20	-		-	NT	1.1	.004
120	0.6		0.6	-	1.2	.004
220	0.5		0.9	-	1.4	.002
320	0.5		0.9	.075	1.4	.002
420	0.4		1.0	.064	1.4	.003
520	0.5		0.8	-	1.3	.003
620	0.7		0.8	-	1.5	.061
720	0.5		0.7	-	1.2	.019
820	0.6		0.7	-	1.3	.010
920	0.7		0.6	-	1.3	.015
1020	0.5		0.6	-	1.1	.023
1120	0.6		0.5	NT	1.1	.040
1220	0.6		0.6	NT	1.2	.040
1320	0.7		0.5	NT	1.2	.040
1420	0.8		0.5	NT	1.3	.040
1520	0.9		0.2	NT	1.1	.040
1620	0.8		0.3	NT	1.1	.040

a Mann Whitney test, $\alpha < .100$, 1-tail probability.

NT Not enough data for meaningful test results.

FIGURE 19

STORMWATER RUNOFF pH INCREASE
WITH MOVEMENT THROUGH THE VEGETATED SWALE



Specific Conductance

Results of runoff composite sampling presented earlier show no significant reductions in specific conductance as a result of vegetated swale treatment. These observations are consistent with results obtained for discrete runoff sampling which appear in Figure 20.

For all volume increments except 20 cf, which is dominated by "first flush" contaminant washoff from the parking lot surface, there exist no distinct decline in specific conductance over the swale length. In fact, specific conductance concentrations actually appear to increase for volume increments beyond 1000 cf. These observations are supported by tests for significant concentration differences between swale stations presented in table 47.

Discrete storm sampling at the 50-swl location reveals an interesting trend which is also apparent in table 47. Note that for every volume increment beyond 120 cf (which is undoubtedly influenced by "first flush effects), the head end of the swale structure is shown to remove more specific conductance than the tail section. In fact, there is an overall consistent increase in specific conductance concentrations in the 50'-swl to 100'-swl section for volume increments 520 through 1220 cf. These results suggest mobilization of dissolved substances contributing to specific conductance in the lower swale section.

FIGURE 20

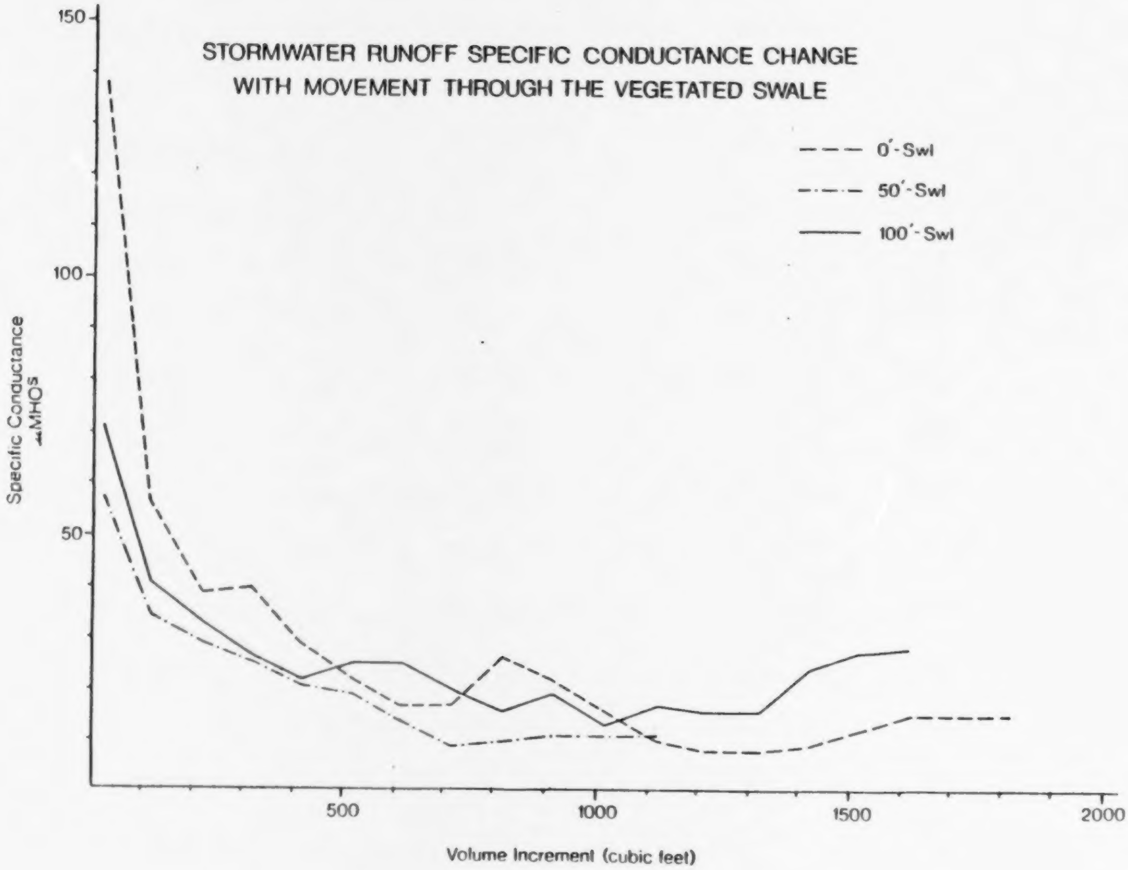

STORMWATER RUNOFF SPECIFIC CONDUCTANCE CHANGE WITH MOVEMENT THROUGH THE VEGETATED SWALE

TABLE 47

GRASSED SWALE DISCRETE RUNOFF SAMPLES
SIGNIFICANCE OF SPECIFIC CONDUCTANCE CHANGE

Volume Increment (cubic feet)	0'-swl to 50' swl Units change	Vs.	50'-swl to 100'-swl Units change	α	0'-swl To 100'-swl Units change	α
20	-		-	-	-67.0	.048
120	-0.17		-17.67	-	-17.8	-
220	-5.58		-0.58	-	-6.2	-
320	-4.33		-1.83	-	-6.1	-
420	-7.50		-3.17	-	-10.7	-
520	-7.80		6.8	.038	+1.0	-
620	0.25		9.25	-	+9.5	-
720	-4.00		27.00	-	+23.0	-
820	-36.00		13.00	-	-23.0	-
920	-17.25		14.75	-	-2.5	-
1020	-11.75		5.25	-	-6.5	-
1120	-0.75		9.25	-	+8.5	.095
1220	1.50		8.50	-	+10.0	.063
1320	-		-	-	+7.7	.055
1420	-		-		+15.3	-
1520	-		-		+15.0	-
1620	-		-		+13.3	.095

Heavy Metals

In addition to pH and specific conductance, grab samples corresponding to the initial runoff (i.e., first sample in collection series), and of the lowest pH encountered during the event, were collected for 5 storm events for analyses of dissolved and total metals concentrations. These data enable an evaluation of swale mediated changes to runoff which is typically highest in heavy metal concentrations and provide an indication of swale effectiveness in dampening peak runoff loads.

Concentration changes to the initial runoff and runoff of lowest pH are compared with stormwater composite concentration changes in Table 48. Note that for each constituent addressed, maximum removal percentages occur in either the initial runoff or lowest pH samples, and not in the stormwater composite sample. These results suggest that swale removal efficiencies improve with increasing metal concentrations during runoff events, thus dampening peak concentrations and impacts produced in the receiving water.

Factors Influencing Swale Performance

Regression analyses have been performed to estimate the influence of runoff pH, storm intensity, precipitation volume, and antecedent dry period on contaminant removal efficiencies of the swale. As shown in table 49, runoff pH and, to a lesser degree, antecedent dry days, are important influencing factors in swale performance.

Results for the heavy metals show high removal efficiency is associated with low stormwater runoff pH levels. As with the rain pH vs. metals analysis presented earlier, Cd is an exception, presumably due to relatively low concentrations with little observed variability.

TABLE 48

STORMWATER RUNOFF GRAB SAMPLES
CONCENTRATION CHANGES

	0'-Swl to 100'-Swl				Stormwater Runoff	
	Initial Runoff		Lowest pH		Composite Samples	
	Overall Removal %	Significance[a] Level $\alpha \leq .10$	Overall Removal %	Significance Level $\alpha \leq .10$	Overall Removal %	Significance Level $\alpha \leq .10$
Cd, total	54	.042	68	.039	56	.062
Cd, diss	51	.083	63	-	42	.024
Cu, total	66	.013	58	.054	48	.001
Cu, diss	68	.028	61	-	53	.006
Pb, total	75	.047	80	.010	65	.000
Pb, diss	75	.008	77	.010	63	.001
Zn, total	79	.005	45	.042	51	.000
Zn, diss	59	.008	37	.074	47	.021
pH (increase)	1.48 units	.024	1.50 units	.010	1.42 units	.000
Spec. Cond.	44	.038	51	.021	1	-

[a] Mann-Whitney test, 1-tail prob.

TABLE 49
MULTIPLE REGRESSION ANALYSIS[a]
SWALE REMOVAL PERMORMANCE (composite samples)
Vs.
RUNOFF pH, STORM INTENSITY, PRECIPITATION VOLUME, ANTECEDENT DRY PERIOD
R^2 CHANGE

	Runoff pH	Storm Intensity	Precipitation Volume	Antecedent Dry Period	Total
Total Coliform	-	-	-	-	-
Fecal Coliform	-	-	-	-	-
Fecal Strep	-	-	-	-	-
BOD	-	-	-	-	-
COD	-	-	-	-	-
TKN	-	-	-	-	-
NA_3	-	-	-	-	-
NO_2+NO_3	(-).60[b]	-	-	(+).21	.81
PO_4	-	-	(+).24	(+).66	.90
P	-	-	-	-	-
Cd, total	(+).93	-	-	-	.93
Cd, diss	-	(-).94	-	-	.94
Cu, total	(-).89	-	-	-	.89
Cu, diss	-	-	-	-	-
Pb, total	(-).63	-	-	(+).17	.80
Pb, diss	(-).79	-	-	-	.79
Zn, total	(-).66	-	-	-	.66
Zn, diss	(+).84	-	-	(+).09	.93
Cl	-	-	-	-	-
Spec. cond.	-	-	-	-	-
Turbidity	-	-	-	-	-
Total solids	-	-	-	(+).53	.53
Susp. solids	-	-	-	-	-

a - Nie, H.M. , and C.H. Hull. SPSS Update 7 - 9. McGraw Hill 1981. New Regression Procedure; default criteria F = .05 for entry of independent variable into regression model.

b - (+) or (-) indicates direction of influence; from correlation analysis.

To a lesser extent, increased antecedent dry periods appear to have a positive influence on swale performance, particularly for PO_4 and total solids removal.

Summary and Conclusions

The quality of stormwater runoff was significantly improved as a result of grassed swale treatment. For the 11 storms sampled during the study period, removal of COD, total residue, NH_3 and $NO_2 + NO_3$ averaged 25%, 33%, 51%, and 32%, respectively. Average removal of both total and dissolved fractions of Cd, Cu, Pb and Zn ranged from 42% for dissolved Cd, to 65% for total Pb. Increases in pH averaged 1.42 units.

Decreases in BOD, turbidity, specific conductance, org-N, and total P were not significant, and increases in suspended residue, PO_4, total and fecal coliforms and fecal streptococci bacteria, were observed.

Heavy metal concentrations in stormwater runoff entering the swale are shown to be significantly correlated with rain pH, with low pH values associated with high metals. Also, very low rain pH, having a median value of 3.47 units, is assumed causative in the observed high ratios of dissolved/total metals concentrations, especially Cu (.917) and Zn (.975).

Swale removal efficiencies for heavy metals are shown to improve with increasing metal concentrations during runoff events, thus dampening peak concentrations and receiving water impacts.

Changes in pH over the swale length were generally constant with no significant differences between the upper and lower 50 feet of the swale. Increases in specific conductance over the swale length for runoff volumes in excess of "first flush" concentration maxima, suggest mobilization of dissolved substances from the swale substrate.

Runoff pH and, to a minor extent the period of dry conditions between storm runoff events, are shown to be important factors influencing swale pollutant removal efficiency.

On the basis of these findings, the following conclusions may be drawn:

Diversion of stormwater runoff through the swale structure is an effective means of reducing many stormwater borne pollutants. Since swale treatment did not include losses to groundwater infiltration, the observed results can be attributed to mechanisms involving plant-soil interactions. Where poor soil permeability or space limitations preclude stormwater infiltration areas, vegetated waterways may still be installed to provide for substantial pollutant reductions prior to receiving water discharge. Also, where provisions are made for groundwater infiltration, increased removal of pollutant loads can be realized.

Dramatic increases in pH as a result of swale treatment are assumed active in the high removal efficiency for heavy metals. These results suggest that acid precipitation effects on receiving water quality may be reduced by vegetated swale treatment, especially in urban areas where plant-soil interactions with stormwater runoff are often limited.

Pollutant removal with distance over the swale length is not significantly different for pH and specific conductance. However, these results do not preclude the possibility of variable removal rates for other constituents, including those in particulate forms. Also, no data are available to characterize swale removal rates with distance during "first flush" periods.

II.3 PAVEMENT VACUUM CONTROL EVALUATION

Introduction

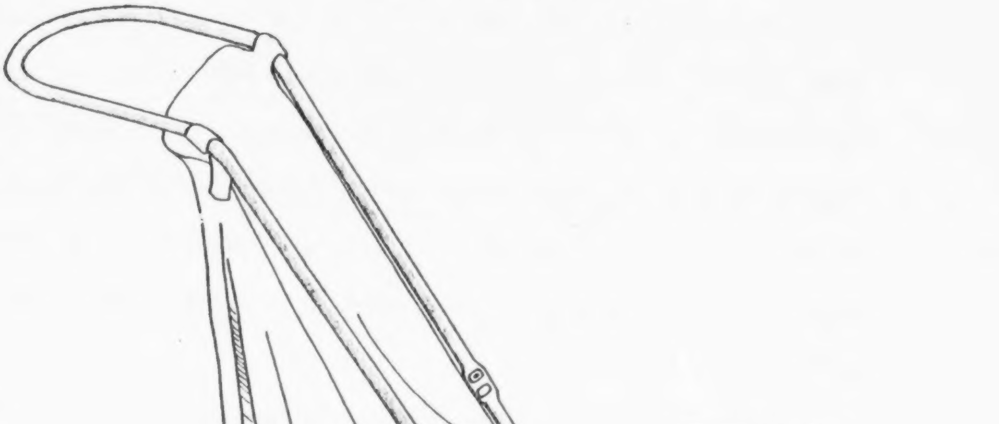
The use of street sweeping devices to control street litter is a common practice in urban areas. The two basic types used are the regenerative air vacuum and broom style mechanical sweepers. A study by the American Public Works Association (1969) found that the most significant component of street litter is associated with the dust and dirt fractions, and that both sweeper types are largely ineffectual in removing these smaller fractions. Sartor and Boyd (1972) have reported that street sweepers do not remove as much as 85 percent of the particle size fraction smaller than 43 microns, within which 25 percent of the total oxygen demand, up to 50 percent of the total heavy metals, 33-50 percent of the algal nutrients, and up to 75 percent of the total pesticides are contained.

Largely by chance, the opportunity was presented to evaluate a vacuum-type sweeping practice at the parking lot site. As a matter of civic pride and aesthetic appeal, management of the commercial supermarket serviced by the parking lot study site has established an unusual parking lot cleaning program. Seven days a week during spring, summer and fall (weather permitting), the entire 0.8 acre parking area is cleaned with a vacuum machine (Figure 21). Equipped with a 5 hp engine and vacuum shrouding fixed at approximately 1-1/2" above the pavement surface, the machine is capable of removing dirt which accumulates on the parking lot surface. By tipping the unit, large solids such as bottles and cans are also removed.

In order to characterize stormwater runoff quality produced from this area prior to any efforts to reduce contaminant washoff, the supermarket

FIGURE 21

PARKING LOT VACUUM CLEANER



management agreed to suspend the vacuuming practice during study phase I. Reactivation of vacuuming during study phase II provided a "before and after" picture which enabled pollutant removal evaluation of this practice.

Data Summary

The sampling strategy employed for this evaluation was identical to that used during phase I at the 1-pkg site. This arrangement enabled comparison of phase I and phase II data sets. The period of data collection for vacuum performance evaluation encompassed 9 storm events occurring between 15 June and 12 August 1982. For comparison with precontrol runoff quality, a subset of the phase I data set was selected which covers the same periods in 1980 and 1981. The reduced phase I data set consists of 13 storm events. Tables 50 and 51 summarize data for precontrol and post control implementation periods (respectively).

TABLE 50
PARKING LOT STORMWATER RUNOFF QUALITY WITHOUT VACUUM CONTROL

Parameter	Number	Mean	Std. dev.	Variance	Maximum	Minimum
Tot. Coli	8	7.11E5	8.06E5	6.50E11	2.40E6	2290.8
Fec. Coli	8	3.58E5	8.40E5	7.06E11	2.40E6	39.81
Fec. Strep	8	9545.728	1.67E5	2.78E8	4.57E5	199.526
BOD	13	11.615	7.137	50.930	22.500	1.400
COD	12	63.050	37.795	1428.439	160.000	28.000
TKN, N	9	1.424	0.660	0.435	2.400	0.630
NH_3, N	12	0.346	0.270	0.073	0.920	0.010
NO_2+NO_3, N	11	0.536	0.331	0.110	1.290	0.070
Diss Ortho P	10	0.022	0.038	0.001	0.116	0.001
Tot. P	10	0.105	0.045	0.002	0.159	0.022
Cd, tot.	10	0.005	0.0003	0.000	0.006	0.005
Cd, diss.	7	0.005	0.0003	0.000	0.006	0.005
Cr, tot.	12	0.020	0.013	0.0002	0.050	0.010
Cr, diss.	7	0.011	0.004	0.000	0.020	0.010
Cu, tot.	12	0.102	0.006	0.000	0.120	0.100
Cu, diss.	7	0.100	0.0	0.0	0.100	0.100
Pb, tot.	13	0.154	0.113	0.013	0.450	0.040
Pb, diss.	7	0.060	0.045	0.002	0.120	0.010
Zn, tot.	11	0.371	0.171	0.029	0.800	0.190
Zn, diss.	7	0.354	0.117	0.014	0.460	0.210
Cl	8	5.000	7.010	49.143	22.000	2.000
pH	11	4.582	0.417	0.174	5.400	4.100
Spec. Cond.	10	39.870	16.522	272.982	71.200	18.100
Turbidity	4	14.000	7.206	51.927	24.000	8.300
Solids, tot.	11	77.691	59.765	3571.851	215.000	5.000
Solids, susp.	11	58.882	59.229	3508.034	191.000	1.000

TABLE 51
PARKING LOT STORMWATER RUNOFF QUALITY WITH VACUUM CONTROL

Parameter	Number	Mean	Std. dev.	Variance	Maximum	Minimum
Tot. Coli	7	1.80E6	4.08E6	1.66E13	1.10E7	933.250
Fec. Coli	7	166.650	193.410	37407.516	467.733	30.199
Fec. Strep	7	71.189	73.132	5348.332	229.086	30.199
BOD	8	5.725	2.306	5.319	8.700	2.500
COD	9	77.222	46.577	2169.444	168.000	16.000
TKN, N	7	0.909	0.418	0.175	1.740	0.460
NH_3, N	8	0.225	0.180	0.032	0.560	0.100
NO_2+NO_3, N	9	0.621	0.368	0.135	1.120	0.220
Diss Ortho P	8	0.017	0.009	0.0001	0.030	0.001
Tot. P	9	0.139	0.071	0.005	0.274	0.042
Cd, tot.	9	0.002	0.002	0.000	0.006	0.001
Cd, diss.	7	0.002	0.001	0.000	0.004	0.001
Cr, tot.	9	0.003	0.0	0.0	0.030	0.030
Cr, diss.	8	0.055	0.028	0.001	0.100	0.030
Cu, tot.	9	0.059	0.029	0.001	0.110	0.030
Cu, diss.	8	0.055	0.028	0.001	0.100	0.030
Pb, tot.	9	0.109	0.053	0.003	0.195	0.025
Pb, diss.	8	0.054	0.036	0.001	0.140	0.025
Zn, tot.	9	0.300	0.216	0.046	0.800	0.909
Zn, diss.	8	0.279	0.212	0.045	0.760	0.060
Cl	9	2.556	1.130	1.278	5.000	2.000
pH	9	4.258	0.380	0.145	4.950	3.580
Spec. Cond.	8	41.025	23.812	567.034	85.000	19.200
Turbidity	9	32.033	36.843	1357.403	120.000	4.600
Solids, tot.	9	106.556	75.675	5726.778	242.000	1.000
Solids, susp.	9	24.556	38.207	1459.778	115.000	1.000

TABLE 52

Parking Lot Vacuum Control Results
(Bacteria Counts or Lbs/Acre/Inch Precip.)

Constituent	Without Control	With Control	Average Change	Overall % Reduction	Significance
BOD_5	2.442	1.014	-1.428	58	.084
COD	11.939	12.539	+0.60	-	-
TKN	0.223	0.155	-0.068	30	-
NH_3	0.052	0.038	-0.014	27	-
NO_2+NO_3	0.101	0.103	+0.002	-	-
PO_4	0.004	0.003	-0.001	25	-
P	0.019	0.023	+0.004	-	-
Pb, Total	0.029	0.018	-0.011	38	-
Pb, Diss.	0.009	0.009	0.000	0	-
Zn, Total	0.057	0.048	-0.009	16	-
Zn, Diss.	0.056	0.044	-0.012	21	-
Cl	0.851	0.428	-0.423	50	-
Residue, Total	12.087	18.093	+6.006	-	-
Residue, Non-Flt.	8.991	4.229	-4.762	53	.044
Coliform, Total	1.06E+13	1.13E+14	+1.02E+14	-	-
Coliform, Fecal	6.11E+12	1.18E+10	-6.10E+12	99	-
Fecal Strep.	1.47E+11	5.95E+09	-1.41E+11	96	.053

Mann-Whitney test, 1-tail prob., $\alpha \leq .10$

Results and Discussion

Stormwater runoff quality and flow data for each study period have been converted to common mass load units of lbs./acre/inch precip., or for the bacteria data - counts/acre/inch precip. These data have been examined to determine if significant decreases exist between data sets. The results are presented in table 52.

As shown, pollutant loads of BOD_5, non-filterable residue, and fecal streptococci bacteria are significantly decreased as a result of daily vacuum cleaning, with average reductions of 58%, 53%, and 96% respectively.

Nutrient loads of TKN, NH_3, and PO_4, are decreased by 30%, 27%, and 25%, respectively, but these reductions are not significant. This is also the case for total Pb and Zn, dissolved Zn, and Cl data where 38%, 16%, 21%, and 50% load reductions are shown. No change is indicated for dissolved Pb.

Results for fecal coliform bacteria show an overall load reduction of 99%. The fact that significance is not achieved indicates extreme data variability which is readily noted in concentration tables 50 and 51. Increased loads of COD, NO_2+No_3, total P, and total coliform bacteria, are observed, although none of these increases are significant.

Summary and Conclusions

Large concentration variability common in stormwater runoff quality is obvious in these results. Generally, such large variability requires a great deal of data for significant trends to be supported statistically. With only 9 storm events available for vacuum control evaluation, these data requirements have likely not been met, therefore, only general indications of pollutant removal performance are presented.

Overall, good removal of non-filterable residue is shown. This result was expected, since larger particle sizes are easily removed with the vacuum cleaner, and performance is obvious when contents of the "collection bag" are examined. Since total residue loads are not reduced by vacuuming, it can be concluded that dissolved solids are not removed to any significant degree from the parking lot surface. These results tend to support the reported ineffectual removal of very small particle sizes which has been experienced in other street sweeping evaluations. Very possibly, BOD_5 and fecal streptococcus loads may be associated with larger particle sizes which results in significant removal.

Load reductions for the other constituents addressed range from 0% for dissolved lead to 99% for fecal coliform bacteria. However, the lack of significance coupled with small sample size precludes meaningful discussion.

Finally, it is difficult to accept the notion that COD, $NO_2 + NO_3$, total P and total residue could increase as a result of vacuuming. Therefore, these results are attributed to expected variability in runoff quality.

II.4 RIVER RUN IMPOUNDMENT CONTROL EVALUATION

Introduction

Source control of storm generated pollution through the use of settling and material treatment processes provided by river-run impoundment has been reported as a viable means of diminishing the impacts of urban stormwater runoff (Alwer et al, 1981). Mill Pond impoundment on the Oyster River, although not designed to act as a sedimentation basin, does in fact trap enough plant nutrient materials to support a luxuriant aquatic macrophyte population. It also removes a considerable quantity of organic and inert materials. Phase II study efforts were directed at quantifying pollutant retention in Mill Pond.

Study Area

Mill Pond (Figure 22) was created by a 15 foot concrete dam on the Oyster River which separates the fresh water river from the tidal estuary. The ponded area is approximately 8.5 acres with mean depth of 1.48 n (4.85 feet), and maximum depth of 4.56 n (15 feet). The volume of water contained is approximately 50,657 m^3 at crest level. Flow rate records from the 5-Oys station used in combination with the stage vs. discharge relationship developed during Phase I of this study (see pg.) indicate detention times ranging between 0.3 and 11.8 days over the period of Phase II study.

Luxuriant aquatic plant growth throughout most of the impoundment is evidence of Mill Pond's affinity for nutrient entrapment. The upper impoundment is virtually overrun with aquatic macrophytes, to the extent that motorized boats cannot pass due to entanglement. This diverse aquatic plant community supports a variety of waterfowl and other aquatic wildlife which add to the aesthetic appeal and have made this area a desirable and much utilized park land.

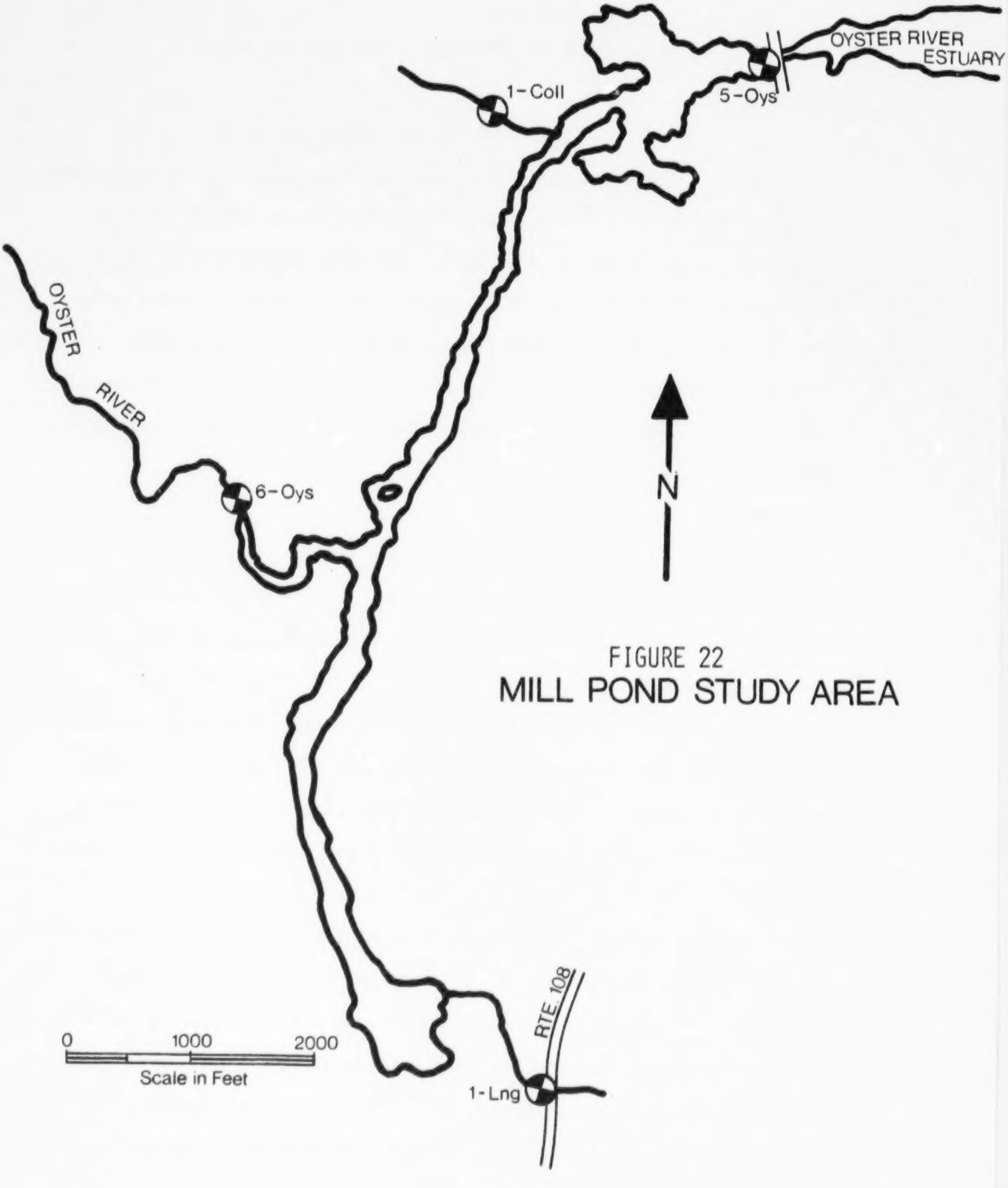

OYSTER RIVER
ESTUARY
5-Oys
1-Coll
OYSTER
RIVER
6-Oys
N
RTE. 108
1-Lng
0
1000
2000
Scale in Feet

FIGURE 22
MILL POND STUDY AREA

Instrumentation and Sampling Procedures

The sampling strategy used to quantify mass retention in Mill Pond involved installation of flow and water quality monitoring stations on all influent tributaries, and the impoundment outlet. Figure 22 presents sampling station locations.

Influent tributary stations included 6-Oys located on the main stem of the Oyster River immediately above the impounded backwater of Mill Pond; 1-Coll located on College Brook approximately 225 meters upstream of Mill Pond; and 1-Lng located on Longmarsh Brook, approximately 250 meters upstream of the impoundment. The outlet from Mill Pond is located at the tidal dam, which marks the location of station 5-Oys.

Water Quality and Flow Monitoring

Water quality and flow data were collected over the period 4 June through 14 October 1982. At stations 6-Oys and 5-Oys, water quality sample collection was automated, using ISCO model 1680 sequential discrete samplers. At both locations sample frequencies were programmed for 6 hour intervals, and collected weekly for transport to the laboratory. This sampling set up enabled estimates of average water quality conditions over the weekly composite period, including both dry weather and storm runoff periods.

Rate of water flow was recorded at the time of water quality sample collection each week. Station 5-Oys was equipped with an ISCO model 1870 flow meter which provided direct reading of stage, or pool level in the impoundment. Stage recordings were then converted to flow ratio out of Mill Pond by means of the stage vs. discharge relationship developed during study phase I.

Station I-Coll was also equipped with a recording flow meter which was used in conjunction with a 4' contracted rectangular weir, yielding direct readings of flow rate. Stormwater flow volumes were determined by analysis of the runoff hydrographs for each of the 6 storm events monitored.

Flow rates at 1-Lng were gauged once weekly, at the time of water quality sample collection. Flow rate and water quality data collected each week were assumed to be representative of average conditions over the period. Stormwater runoff sampling was not performed since the Longmarsh Brook catchment is generally forested with only minor low density residential development and the small drainage area of 2.2 mi.^{2} contributed very little stormwater runoff and base flow input to Mill Pond.

Flow rates at 6-Oys were estimated by subtracting influent flows at 1-Coll and 1-Lng from 5-Oys outlet flows. This method of approximation was selected rather than attempting to install a suitable primary device in the flow channel, since major site modifications could not be accommodated. It should be noted that volume losses due to evaporation in Mill Pond have been ignored.

Stations 1-Coll and 1-Lng were grab sampled for water quality determinations once weekly on the day of 6-Oys and 5-Oys sample collection. In addition to grab sampling at 1-Coll, stormwater runoff composite sampling was performed in order to approximate average stormwater loads from the College Brook catchment. At each station, on site analysis of pH, dissolved oxygen and specific conductance were performed. Grab samples for bacteria were also collected.

Data Summary

Water quality data for each of the Mill Pond tributaries are summarized in Tables 53, 54 and 55. Table 56 summarizes Mill Pond outlet water quality data measured at 5-Oys. Stormwater runoff quality data collected at 1-Coll have been used to produce the average loading data which are presented in table 57.

TABLE 53

MILL POND TRIBUTARY INPUT WATER QUALITY DATA SUMMARY
6-OYS (OYSTER RIVER)

Parameter	No. of Entries	Mean	Std. Dev.	Maximum	Minimum
Tot. Coli	16	310.562	44.061	363.000	236.000
Fec. Coli	16	233.312	59.844	336.00	130.000
Fec. Strep	16	311.312	52.009	436.000	236.000
BOD	16	2.181	2.732	12.000	0.300
COD	18	30.944	15.082	67.000	10.000
TKN, N	17	0.731	0.342	1.720	0.260
NH_3	9	0.119	0.050	0.250	0.100
NO_2 + NO_5, N	19	0.413	0.153	0.690	0.180
PO_4	7	0.010	0.009	0.027	0.001
Tot. P	19	0.064	0.066	0.310	0.003
Cd tot	19	0.002	0.001	0.006	0.001
Cr tot	19	0.036	0.017	0.100	0.030
Cu tot	19	0.035	0.016	0.100	0.030
Pb tot	19	0.024	0.034	0.150	0.010
Sn tot	2	0.015	0.007	0.020	0.010
Zn tot	19	0.097	0.140	0.600	0.020
Chloride	14	36.357	10.595	51.000	18.000
Solid, tot	18	128.944	26.098	173.000	71.000
Solid, sus.	15	6.062	4.864	15.000	1.000

TABLE 54

MILL POND TRIBUTARY INPUT WATER QUALITY DATA SUMMARY
6-OYS (OYSTER RIVER)

Parameter	No. of Entries	Mean	Std. Dev.	Maximum	Minimum
Tot. Coli	16	324.812	50.445	436.000	263.000
Fec. Coli	16	212.000	47.705	297.000	148.000
Fec. Strep	16	332.312	57.918	418.000	263.000
BOD	17	2.212	0.868	3.700	0.900
COD	18	41.222	13.406	69.000	20.000
TKN, N	17	1.058	0.284	1.450	0.490
NH_3	6	0.120	0.028	0.170	0.100
$NO_2 + NO_5$, N	19	0.152	0.067	0.290	0.080
PO_4	5	0.074	0.033	0.126	0.042
Tot. P	19	0.195	0.098	0.470	0.052
Cd tot	19	0.001	0.001	0.005	0.001
Cr tot	19	0.030	0.0	0.030	0.030
Cu tot	19	0.034	0.016	0.100	0.030
Pb tot	19	0.018	0.013	0.055	0.010
Sn tot	0	-	-	-	-
Zn tot	19	0.096	0.132	0.390	0.030
Chloride	12	26.833	4.648	35.000	19.000
Solid, tot	18	152.667	36.827	205.000	84.000
Solid, sus.	15	40.67	5.775	20.000	1.000

TABLE 55

MILL POND TRIBUTARY INPUT WATER QUALITY DATA SUMMARY
1-COLL (COLLEGE BROOK)

Parameter	No. of Entries	Mean	Std. Dev.	Maximum	Minimum
Tot. Coli	17	404.059	70.399	497.000	263.000
Fec. Coli	17	292.765	63.237	463.000	160.000
Fec. Strep	17	329.765	57.526	436.000	263.000
BOD	18	1.500	0.650	2.700	0.200
COD	19	21.100	10.715	38.000	7.900
TKN, N	17	0.841	0.350	1.440	0.440
NH_3	6	0.120	0.440	0.210	0.100
NO_2 + NO_5, N	19	0.767	0.128	1.170	0.590
PO_4	5	0.025	0.034	0.086	0.006
Tot. P	19	0.134	0.208	0.980	0.040
Cd tot	19	0.002	0.001	0.005	0.001
Cr tot	19	0.030	0.0	0.030	0.030
Cu tot	19	0.039	0.022	0.100	0.030
Pb tot	19	0.036	0.026	0.100	0.010
Sn tot	-	-	-	-	-
Zn tot	19	0.102	0.115	0.400	0.030
Chloride	11	93.182	15.696	105.000	50.000
Solid, tot	18	338.278	71.898	488.000	202.000
Solid, sus.	15	2.667	1.543	6.000	1.000

TABLE 56

MILL POND OUTLET WATER QUALITY DATA SUMMARY
5-OYS (OYSTER RIVER)

Parameter	No. of Entries	Mean	Std. Dev.	Maximum	Minimum
Tot. Coli	16	294.437	51.711	363.000	163.000
Fec. Coli	16	201.062	54.493	336.000	148.000
Fec. Strep	16	279.000	85.651	432.000	148.000
BOD	17	2.071	2.457	11.000	0.100
COD	18	29.333	8.088	45.000	16.000
TKN, N	17	0.751	0.298	1.750	0.520
NH_3	9	0.180	0.017	0.150	0.100
$NO_2 + NO_5$, N	19	0.245	0.113	0.560	0.050
PO_4	8	0.014	0.010	0.036	0.007
Tot. P	19	0.067	0.075	0.370	0.020
Cd tot	19	0.002	0.001	0.006	0.001
Cr tot	19	0.031	0.005	0.050	0.030
Cu tot	19	0.035	0.016	0.100	0.030
Pb tot	19	0.022	0.023	0.100	0.010
Sn tot	2	0.015	0.007	0.020	0.010
Zn tot	19	0.075	0.091	0.360	0.030
Chloride	14	37.143	10.354	53.000	20.000
Solid, tot	18	128.611	25.535	164.000	75.000
Solid, sus.	15	7.344	13.067	53.000	1.000

Results and Discussion

Water quality and flow data were used to calculate daily mass loads into and out of Mill Pond. Mass loads included estimates of stormwater loads generated from the College Brook catchments. Stormwater runoff mass loads for College Brook are presented in table 57. Note that the loading rates are presented in terms of lbs./inch precipitation or coliform counts/inch precipitation. These loading rates represent an average of 6 storms monitored. Rainfall records available from the NOAA weather station in Durham provided weekly precipitation values. These values were applied to the stormwater loading rate to estimate weekly stormwater loads at 1-Coll, which were added to the base flow loads from the catchment.

Table 58 presents a summary of influent and outlet mass loads for Mill Pond for those weekly quality constituents which were routinely above laboratory detection limits. These results show reductions of total and fecal coliform, NO_2 + No_3. total P, Zn and total solids were significant, averaging 59.6%, 52.6%, 25%, 11.4%, 28.5%, and 7.1% (respectively), expressed as percentage of influent pollutant load removed. Removal of BOD, COD, and load were not significant, averaging 4.3%, 10.1%, and 34.2% (respectively), and mass loads of TKN, PO_4 and Cl actually increased in Mill Pond, although not significantly.

Removal of coliform bacteria as a result of Mill Pond impoundment is perhaps most beneficial in terms of protecting the downstream shellfishery. Estuary water quality monitoring (see pgs. 198-201) reveals frequent violations of coliform bacteria standards for shellfish waters. Results of this analysis suggest coliform concentrations could be more than 50% greater in the estuary were it not for treatment provided by Mill Pond.

Assuming significant mass load retention rates can be applied over a year's period, approximately 2,555 lbs. of NO^2 + NO3, 498 lbs. of P,

TABLE 57

1-COLL (COLLEGE BROOK) STORM LOADING DATA

Parameter	No. of Entries	Lbs/Day Mean	Std. Dev.	Maximum	Minimum
Tot. Coli	6	6.60×10^{-14}	9.40×10^{-14}	2.33×10^{-15}	4.72×10^{-9}
Fec. Coli	6	1.53×10^{-13}	2.64×10^{-13}	6.58×10^{-13}	4.72×10^{-9}
Fec. Strep	6	1.12×10^{-13}	1.48×10^{-13}	3.53×10^{-13}	4.72×10^{-9}
BOD	5	76.233	33.799	113.071	27.091
COD	5	697.014	348.179	1190.648	250.071
TKN, N	6	24.616	14.303	49.100	10.309
NH_3	6	3.261	2.030	6.510	1.042
NO_2 + NO_5, N	6	14.734	6.817	22.452	6.356
PO_4	5	0.560	0.366	1.028	0.118
Tot. P	6	3.230	1.783	5.321	1.073
Cd, tot	6	0.057	0.048	0.137	0.010
Cr, tot	6	0.679	0.317	1.028	0.313
Cu, tot	6	0.679	0.317	1.028	0.313
Pb, tot	6	0.870	0.574	1.941	0.313
Sn, tot	3	0.607	0.131	0.685	0.457
Zn, tot	6	1.550	0.675	2.361	0.417
Chloride	6	1628.389	720.380	2466.993	622.810
Solid, tot	6	6299.457	3008.299	9833.709	2255.001
Solid, sus.	6	555.395	745.460	2055.352	41.678

TABLE 58

Mill Pond Pollutant Removal

(Lbs or MPN/Day)

		BOD	COD	TKN	NO_2 + NO_3	PO_4	P	Pb	Zn	Cl	TSS	Total Coli	Fecal Coli	Fecal Strep
Total Inflow	- Maximum	1,539	10,159	229	79	2.927	127.5	13.89	83.29	5,410	28,417	4.22E+14	1.87E+14	3.26E+14
	Minimum	9	196	5	4	0.203	0.636	0.170	0.42	513	2,037	1.53E+10	1.53E+10	1.53E+10
	Average	230	2,786	72	28	1.145	11.4	2.280	10.02	1,724	10,343	1.54E+14	2.08E+13	8.52E+13
Outflow	- Maximum	1,659	5,883	617	57	2.308	130.4	4.05	54.31	5,656	27,494	4.06E+14	2.49E+13	1.22E+15
	Minimum	4	228	6	6	0.237	0.336	0.09	0.33	434	1,454	1.53E+10	1.53E+10	1.53E+10
	Average	220	2,505	83	21	1.233	10.1	1.50	7.16	1,752	9,610	7.18E+13	5.99E+12	1.36E+14
Average Removal		10	281	-12	7	-0.088	1.363	0.782	2.85	-28	732	8.27E+13	1.48E+13	-5.08E+13
Removal as % of Inflow		4.3	10.1	-15.3	25.0	-7.7	11.4	34.2	28.5	-1.6	7.1	59.6	52.6	-36.3
Significance*		-	-	-	.005	-	.017	-	.073	-	.001	.005	.060	-

*Paired t-test, 1-tail prob., $\alpha \le .1$

1040 lbs. of Zn, and 267,180 lbs. of solids can be expected to accumulate in Mill Pond. Evidently these materials, including organic nutrients associated with the solids, are responsible for the observed prolific aquatic macrophyte growth in Mill Pond. It should be noted that these yearly projections ignore the potential for seasonally high river velocities which may result in scouring of Mill Pond sediments. However, greater water volumes associated with potential scouring velocities will tend to reduce water quality impacts due to increased dilution in the receiving stream.

Intuitively, contaminant removal in Mill Pond is expected to be the result of reduced river velocities through the impoundment which allows for settling of solid materials. Measures of rank correlation have been used to determine if a trend exists between Mill Pond pollutant removal efficiency and river flow rate as measured at 5-Oys. Results of the analysis are shown in Table 59. As indicated, removal efficiencies of TSS, Cl, NO_2+NO_3, and total coliform bacteria are shown to be significantly improved as a result of decreased flow rate through the impoundment.

Implicit in these results is the reduced ability to trap solids and other potential pollutants during high flow periods - including stormwater runoff events. Thus, net removal of these substances is significant, however, the magnitude of removal varies with river flow rates and associated detention times in Mill Pond.

TABLE 59

MILL POND POLLUTANT REMOVAL EFFICIENCY

5-OYS Vs. FLOW RATE

Constituent	N	% Removal vs. 5-Oys Flow Rate Rank Correlation[a]	$\alpha <$ .100
BOD	16	+.184	-
COD	17	+.017	-
TSS	18	-.690	.005
Cl	14	-.853	.005
Pb	19	-.077	-
Zn	19	+.179	-
PO_4	7	+.216	-
P	19	-.192	-
TKN	17	-.165	-
$NO_2 + NO_3$	19	-.632	.005
Total Coli	19	-.501	.025
Fecal Coli	19	-.128	-
Fecal Strep	19	-.116	-

a - Spearmans Rank Correlation

Summary and Conclusions

Results of pollutant removal efficiencies of Mill Pond show considerable reduction of influent pollutant loads. Reductions of total and fecal coliforms, NO_2 + No_3, total P, Zn and total residue, were significant in terms of percentage of influent loads removed.

Reductions of BOD, COD, and Pb were not significant. Observed net increases in TKN, PO_4 and Cl loads were also not statistically significant.

Removal of total and fecal coliform bacteria, (averaging 59.6% and 52.6% respectively), is quite beneficial in terms of protecting the downstream estuary shellfishery.

Although not large in terms of percentage of influent load removed, mass retention of organic materials and other plant nutrients in Mill Pond results in the observed prolific aquatic macrophyte growth and occasional low dissolved oxygen levels in the pond.

Correlation analysis reveals a trend of improved removal efficiencies associated with decreased flow rates through Mill Pond, indicating that detention time is critical in contaminant removal.

SECTION III

Oyster River Estuary Computer Model Applications

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III.1 INTRODUCTION

Computer modeling was performed to estimate impacts of stormwater runoff in the Oyster River Estuary, which feeds into Great Bay, N. H. (Figure 23). The approach involved verification of model performance, followed by simulations of estuary water quality conditions resulting from projected stormwater runoff pollutant loading scenarios. The impacts are defined as violations of New Hampshire water quality standards for coliform bacteria and dissolved oxygen. Additionally, having evaluated performance efficiencies of stormwater runoff degradation control measures, computer modeling was intended to estimate improvements to estuary water quality resulting from control implementation.

Water flows were simulated using a detailed one-dimensional tidal model calibrated using site-specific basin geometry and channel friction coefficients. The Oyster River estuary was divided into 24 distinct reaches, each having a central channel flanked by periodically flooded mudflats. The model operated on a timestep of less than one minute and solved explicitly the continuity and momentum equations for tidal height and water flows. The water flows so determined were used by a linked constituent model to transport constituents throughout the study site, concurrently tabulating the effect of mortality on coliform populations or of decay processes on suspended organic material. BOD was linked to analysis of oxygen transport and reaeration.

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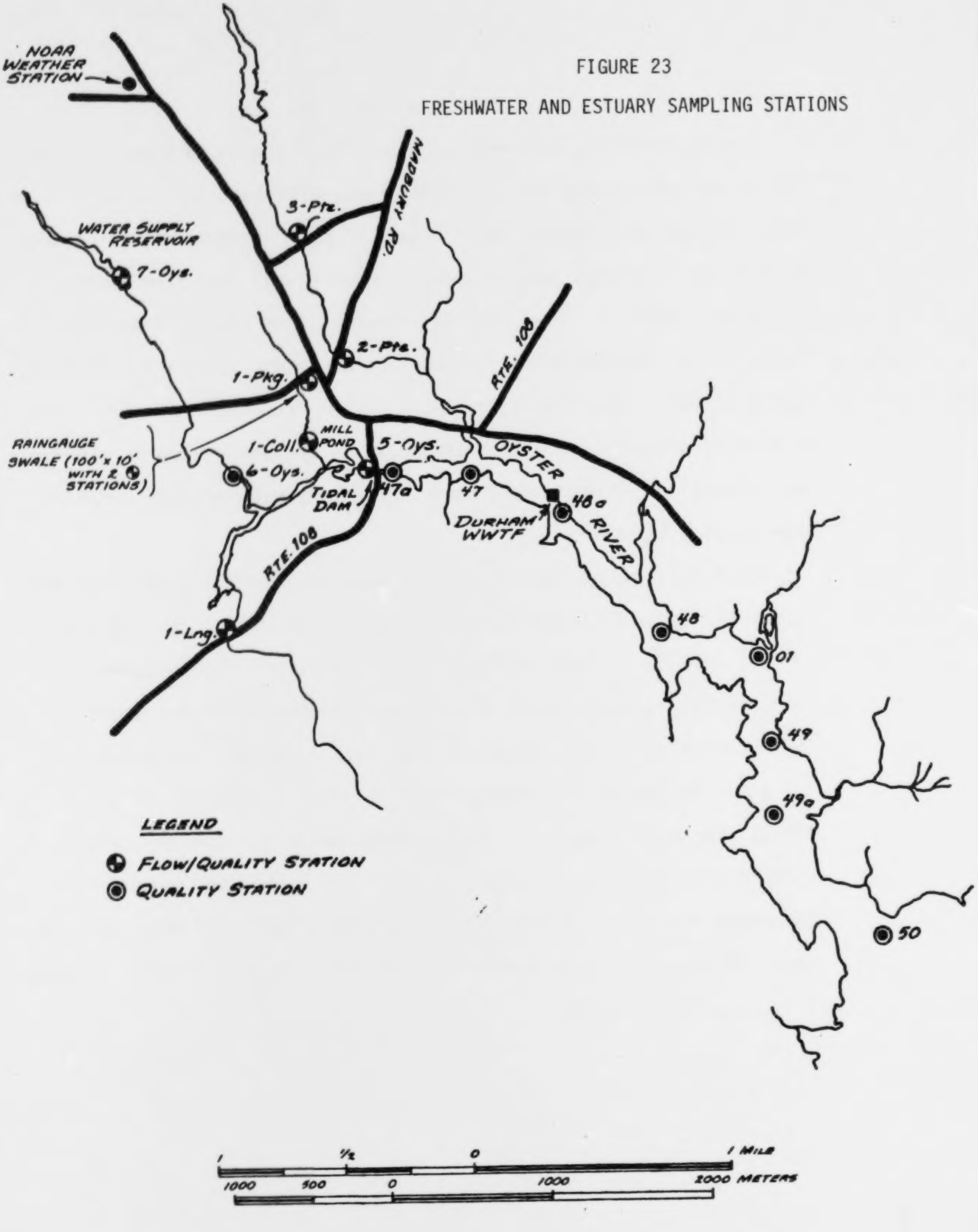
FIGURE 23

FRESHWATER AND ESTUARY SAMPLING STATIONS


NOAA WEATHER STATION
MADBURY RD.
3-Ptc.
WATER SUPPLY RESERVOIR
7-Oys.
RTE. 108
2-Ptc.
1-Pkg.
MILL POND
1-Coll.
5-Oys.
RAINGAUGE
SWALE (100' x 10' WITH 2 STATIONS)
6-Oys.
TIDAL DAM
47a
47
OYSTER RIVER
48a
DURHAM WWTF
RTE. 108
1-Lng.
48
01
49
49a
50
LEGEND
FLOW/QUALITY STATION
QUALITY STATION
1
1/2
0
1 MILE
1000
500
0
1000
2000 METERS

III.2 MODEL DESCRIPTION

The complex physics of water movement in estuaries warrants the use of a reasonably detailed tide-propagation model. The model chosen was developed by Lee (1971) at the Massachusetts Institute of Technology and subsequently was expanded by Schmidt (1981) in his doctoral research on the Oyster River. The computer simulation operates in one, longitudinal dimension and enables water heights to be calculated at discrete intervals along the river. In addition, it estimates both longitudinal water flow in the central channel, and the volume of water stored by the mudflats during flooding stage. Generating such hydrodynamic information is the first step in a larger modeling endeavor, and, when linked to a constituent model, the hydrodynamic simulation can produce a spatial and temporal distribution of concentration throughout the study site.

The hydrodynamic model solves explicity two fundamental relationships, the continuity and momentum equations. The governing equations have been summarized elsewhere (Schmidt 1981, Najarian and Harleman 1975, and Lee 1971) but deserve repetition.

a). The differential form of the continuity equation is:

$$\underset{\substack{\text{Change in}\\\text{Volume}}}{b\frac{\partial H}{\partial t}} \quad + \quad \underset{\substack{\text{Longitudinal}\\\text{Flow Gradient}}}{\frac{\partial Q}{\partial x}} \quad - \quad \underset{\substack{\text{Freshwater}\\\text{Inflow}}}{q} \quad = \quad 0$$

where, b = the total width of channel and marsh

$\partial H/\partial T$ = the time rate of change in water height

$\partial Q/\partial X$ = longitudinal rate of change of tidal flow at a cross section

q = exogenous freshwater inflows per unit length of river

b). The differential form of the momentum equation is:

$$\frac{\partial Q}{\partial t} + \frac{2Q}{A}\left(q - b\,\frac{\partial H}{\partial t}\right) + g\frac{\partial H}{\partial x}A + g\frac{Q\ Q}{AC^2R} = 0$$

Local Acceleration	Advective Acceleration	Force due to Surface Slope	Friction Force

where, dQ/dT = flow rate change per unit length of river

g = acceleration

dH/dx = surface slope

A = cross-sectional area of flow

R = hydraulic radius

C = Chezy function coefficient =

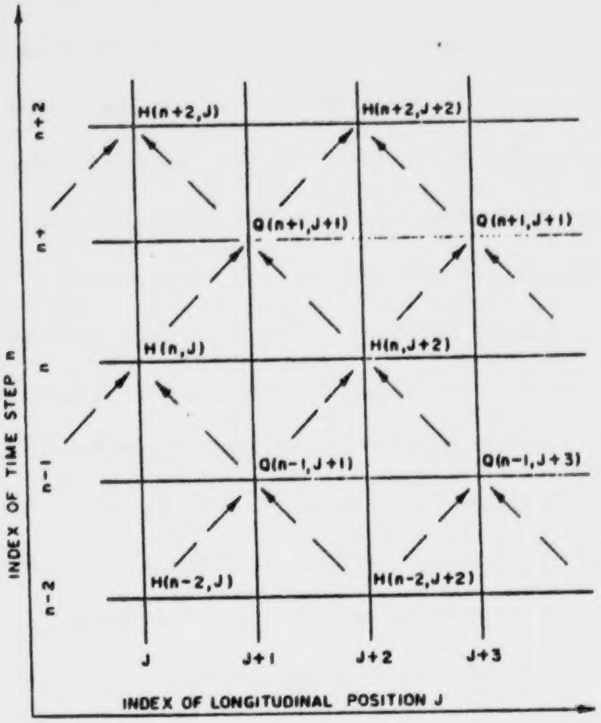
n = Manning resistance coefficient = $\frac{1.49}{n} \quad R^{\frac{1}{6}}$

p = density of water

The model solves explicitly a finite-difference version of each of the above two equations. It estimates the two unknowns, H and Q, using the solution scheme depicted in Figure 24. Calculations for tide heights are made using the continuity equation at odd-numbered stations and timesteps while flows are predicted via the momentum equation at the even-numbered counterparts.

FIGURE 24

HEAD AND FLOW SOLUTION SCHEME


H(n+2,J)
H(n+2,J+2)
Q(n+1,J+1)
Q(n+1,J+1)
H(n,J)
H(n,J+2)
Q(n-1,J+1)
Q(n-1,J+3)
H(n-2,J)
H(n-2,J+2)
n+2
n+1
n
n-1
n-2
J
J+1
J+2
J+3
INDEX OF TIME STEP n
INDEX OF LONGITUDINAL POSITION J

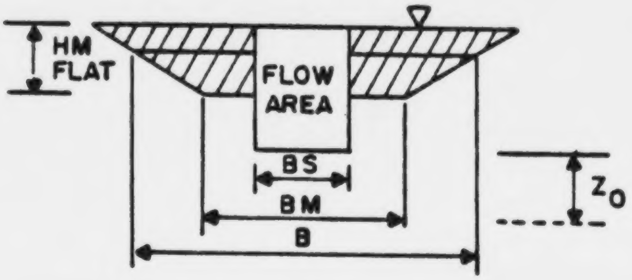
NOTE : ARROWS INDICATE DATA FLOW FOR EXPLICIT TIME-STEPPING

The simulation requires information on the cross-sectional geometry of the basin being modeled. A single measured transect, exaggerated vertically, might appear as the curved line in figure 25. The rectangular configuration overlaying the curved line typifies the geometry used in the simulation. Equivalent cross-sectional area establishes the link between idealized and measured morphology. H is predicted using information about both the channel and marsh; however, since flow is confined to the channel proper, the Q determinations rely solely on parameters describing the central portion of each transect. The river was represented by 24 equally-spaced (at 750 feet) transects. The geometry of these transects is given in Table I, and applies to all simulations presented below.

The forcing functions for the model are oscillating tide height at the estuary mouth and freshwater inflows at 5-Oys, 2-Pte, and the wastewater treatment facility. The tide height downriver varied with an amplitude of ± 3 feet, from mid-flood to mid-flood, centered at 21 ft. (datum in Table 60). For each cycle a constant freshwater inflow is applied. All forcing functions were applied until results for height and tidal flows from one cycle resembled those of a previous cycle within an acceptable margin of difference. To obtain this quasi-steady-state, a timestep of 15 to 25 seconds is typically chosen, its specific size determined by the available computer space and the stability criterion of the model. For estuaries such as the Oyster River, this stability relationship involves the distance between adjacent cross-sections and tide height. A timestep of 23.5 seconds was used in this analysis.

TABLE 60

IDEALIZED GEOMETRY
OYSTER RIVER

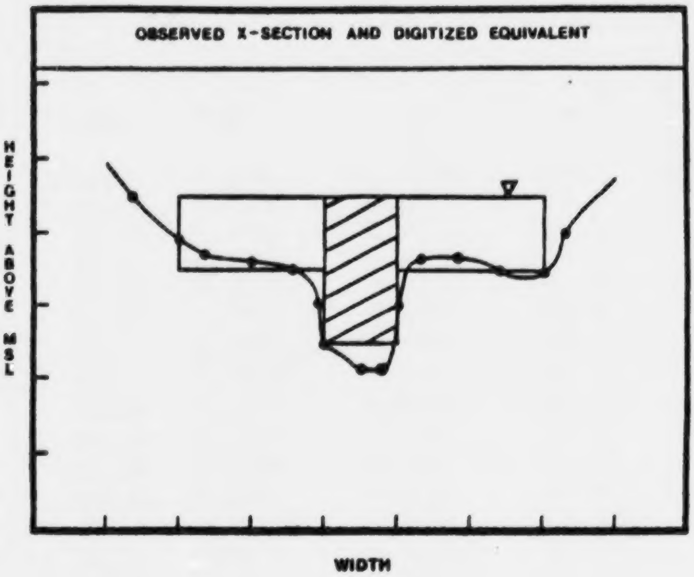


	ZO	B	BS	DS	BM
1 (Mouth)	0.00	3000.0	550.0	5.30	2600.0
2	0.00	2200.0	400.0	5.30	1800.0
3	0.00	1400.0	275.0	5.30	1210.0
4	0.00	1400.0	275.0	5.30	1210.0
5	4.50	1400.0	275.0	5.30	1210.0
6	4.50	1750.0	275.0	5.30	1525.0
7	7.00	1500.0	275.0	5.30	1300.0
8	7.00	1250.0	275.0	5.30	1070.0
9	7.00	850.0	250.0	4.30	660.0
10	7.00	850.0	290.0	4.30	660.0
11	8.00	850.0	250.0	4.30	660.0
12	8.60	850.0	200.0	4.30	660.0
13	12.00	850.0	150.0	4.30	660.0
14	13.00	1050.0	170.0	4.30	850.0
15	14.00	850.0	150.0	4.30	660.0
16	14.00	650.0	125.0	4.30	500.0
17	14.00	450.0	100.0	4.30	355.0
18	14.00	450.0	100.0	4.30	355.0
19	14.00	450.0	100.0	4.30	355.0
20	14.00	600.0	100.0	4.30	470.0
21	14.00	650.0	75.0	4.30	500.0
22	14.00	500.0	75.0	4.30	400.0
23	14.00	350.0	75.0	4.30	282.0
24 (Head)	20.00	350.0	75.0	4.30	282.0

Note: All units in feet. Datum is at 21.0 feet.

FIGURE 25

CROSS-SECTIONAL BASIN GEOMETRY


OBSERVED X-SECTION AND DIGITIZED EQUIVALENT
HEIGHT ABOVE MSL
WIDTH

Collectively, the effect of the friction term in the momentum equation is to delay longitudinal propagation of the tide. Throughout the study site, however, tide heights are more or less synchronous, thereby suggesting a small frictional effect. The value employed for Manning's n was 0.02. The presumed distribution of these coefficients was constant throughout the system and, like the geometric parameters, were applied consistently to all simulations.

Unfortunately, there were no measured internal flows to compare to prediction. As expected, though, maximum flood and ebb flows derived from the simulation (±6100 ft.3/sec) are to be found at the estuary mouth. In contrast, much less tidal water flows past sites located upriver. As we shall see, this phenomenon makes the seaward boundary quite important in making judgements about the behavior of pollutants within the estuary. The residence time of water calculated using a tidal prism approximation [maximal volume at flood stage divided by volume of tidal prism (Dyer 1973)] approached 1.5 tidal cycles.

The constituent model adheres to the one-dimensional conservation of mass principal for conservative substances:

$$\frac{\partial C}{\partial t} = \frac{1}{A} \qquad \frac{\partial}{\partial x} \; (AE \; \frac{\partial C}{\partial x} \qquad - \qquad \frac{1}{A} \; \frac{\partial (QC)}{\partial x}$$

Local Concentration Change	Dispersion	Advective Transport

where E is the dispersion coefficient (from Najarian and Harleman 1975, Lee 1971). Schmidt (1981) had performed a detailed analysis of the dispersion term used in an implicit model for dissolved constituents in the Oyster River. His study confirmed that dispersion is a complex physical phenomenon and that modeling these mixing effects requires a rich data set of constituent concentrations collected over time and space. Since these data were not available for the tidal cycles simulated in this study, an explicit solution scheme was utilized, with a time step approximately one order of magnitude lower than that of Schmidt's implicit model. Relatively short time steps tend to accentuate "numerical dispersion," compensating for the lack of a specific dispersion term in the current constituent model.

For the purposes of this study, the above equation required simplification, and the dispersive term was excluded from our analysis. The appropriate determination of the dispersion coefficient (which varies in magnitude over both space and time) requires detailed information regarding the distribution of a conservative tracer throughout the estuary (Schmidt 1981, Thatcher and Harleman 1972). Salinity is the typical choice, however, no such data were available for current simulation. Schmidt (1981) does offer tidally-averaged coefficients for the Oyster River in hydrodynamic settings similar to that of July 1981. However, these are well below the bulk of measured dispersion coefficients tabulated elsewhere (O'Connor 1980). Thus, the constituent equation may reasonably consider the first and last terms only. When material is injected either laterally or from upriver, the equation also will show an external source term.

The constituent model uses the same idealized transects as the model for water flow (Figure 25), but now the transects bound rectangles which may be thought of as a series of discrete, continuously-mixed volumes. The timestep and longitudinal distance between adjacent transects in the constituent model are twice those used by the water movement model. This allows direct coupling of material fluxes to water flows calculated at alternative timesteps by the hydrodynamic model. In order to solve the conservation of mass equation explicitly, a series of finite difference equations was formulated to relate Q and C in each 'box.' There are four specific forms, each accounting for a particular combination of directional water flow and constituent concentration in the source water from which that flow originated. Therefore, to simulate mass transfer in a timestep (n) during flood tide, the following equation is used:

$$C(n,J) \quad = \quad C(n-2,J)$$

updated concentration   previous concentration

$$+\, Q(n-2,J-1) * C(n-2,J-2)/A\Delta x$$

flux from adjacent downriver 'box'

$$-Q(n-2,J+1) * C(n-2,J)/A\Delta x$$

flux to adjacent upriver 'box'

The equation's basic structure is shared by ebbing tides and slack tides, those short periods of time when the two boundary flows associated with a particular box become bidirectional. To accomodate these conditions requires but simple modification of the indices for J.

The upriver and downriver forcing functions are now material fluxes into the study site. Each flux is calculated as the flow of water across the boundary multiplied by the measured concentration of the constituent just outside the study site. To determine the impact of this flux on concentration inside the study site the flux is immediately divided by the volume of the 'box' to which it was added, either at the estuary mouth or at the upriver volumes adjacent to 5-Oys and 2-Pte. As before, the forcing functions are applied repetitively until a quasi-steady state is attained, this time with regard to concentration.

When biotically-active substances are considered, the above constituent equations then contain either an internal material source or sink term. The nature of kinetic processing can take many forms, from zero-order constant source or sink terms, to Michaelis-Menton type reaction velocities characteristic of many nutrient uptake processes. For the present study, all biotic decay coefficients, for fecal and total coliforms and for BOD, were considered to be first order. The rates at 23°C were 2.18/day, and 0.27/day (base e). No specific phytoplankton or benthic sediment oxygen exchanges were modeled.

III.3 MODEL VERIFICATION

Data requirements for verification of the detailed model include accurate timeseries of concentration change at both the upriver and downriver boundaries (5-Oys and 50-Oys; as forcing functions) and at various sites along the longitudinal axis of the river (for calibration purposes). Although useful for detecting patterns of water quality change, information available through the estuary monitoring phase of the study (table 61) could not satisfy these model requirements. In light of the data limitations, educated assumptions were necessary concerning the magnitude and duration of material influx across the study site boundaries. It must be realized that by making such assumptions quantitative rigor is sacrificed, but the exercise is still instructive in examining the qualitative behavior of the estuary. Also, insight can be gained concerning the system's sensitivity to pollution loading.

The storm events analyzed for verification purposes occurred over the period 13 July through 15 July 1981. A total of 0.8 inches of precipitation fell in two discrete storm events during this time. Provided with average stormwater loading at the freshwater input locations (table 62), model simulation results have been compared with the observed estuary water quality conditions of 15 July 1981.

Estuary model simulation encompassed five tidal cycles. The first and last cycles approached more or less steady state conditions in terms of both freshwater inflow and boundary concentration of bacteria and BOD. The intervening cycles experienced stormwater runoff enhanced freshwater inflows and constituent loading from either the Pettee Brook or from the upriver portion of the Oyster River.

TABLE 61

OYSTER RIVER ESTUARY SAMPLING DATA - 1981

1981 SAMPLING DATA

48-A-OYS/OYSTER RIVER
43 08 06 70 52 12
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	6	317.833	21978.3	148.251	446.000	118.0
FEC COLI	MPN	TUBECODE	7	264.286	22052.8	148.502	504.000	48.0
FEC STRP	MPN-KFBR	TUBECODE	7	208.714	19246.3	138.731	418.000	48.0
BOD	5 DAY	MG/L	8	2.512	4.56250	2.136	3.400	1.0
DO		MG/L	8	9.387	1.88513	1.373	11.6	7.1
TKN	N	MG/L	8	0.920	0.51696	0.719	2.500	0.1
NH3+NH4-	N TOTAL	MG/L	8	0.710	0.300304	0.548	1.700	0.1
NO2&NO3	N TOTAL	MG/L	8	0.141	0.00490	0.070	0.230	0.0
ORTHOPO4	PO4	MG/L	8	0.164	0.03686	0.192	0.580	0.0
PHOS-TOT		MG/L P	8	0.238	0.07182	0.268	0.872	0.0
LAB	PH	SU	8	7.612	0.02993	0.173	7.800	7.3
CONDUCTVY	AT 25C	MICROMHO	8	23912.500	78846958.7	8879.581	38000.000	12500.
TURB	TRBIDMTR	HACH FTU	8	11.337	140.921	11.871	40.000	4.8
RESIDUE	TOT VOL	MG/L	8	26773.399	72398928.7	8508.756	38936.992	107[illegible]
RESIDUE	VOL NFLT	MG/L	8	9.812	34.1406	5.843	20.000	[illegible]
SALINITY		0/00	9	16.222	30.5698	5.529	24.500	[illegible]

1981 SAMPLING DATA

48-OYS/OYSTER RIVER
43 07 54 70 53 42
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	176.286	8390.19	91.598	297 000	48.0
FEC COLI	MPN	TUBECODE	76	116.500	2554.70	50.544	195.000	48.0
FEC STRP	MPN-KFBR	TUBECODE	76	113.167	4179.36	64.648	215.000	48.00
BOD	5 DAY	MG/L	8	1.362	0.08821	0.297	1.800	1.00
DO		MG/L	8	9.387	1.95720	1.399	11.600	7.50
TKN	N	MG/L	7	0.203	0.00774	0.088	0.340	0.12
NH3+NH4-	N TOTAL	MG/L	7	0.141	0.00774	0.088	0.340	0.10
NO2&NO3	N TOTAL	MG/L	8	0.097	0.00423	0.065	0.200	0.00
ORTHOPO4	PO4	MG/L	7	0.030	0.00023	0.015	0.048	0.00
PHOS-TOT		MG/L P	7	0.063	0.00005	0.007	0.076	0.05
LAB	PH	SU	8	7.787	0.02132	0.146	8.000	7.50
CONDUCTVY	AT 25C	MICROMHO	8	26487.500	91929820.7	9588.004	38000.000	13000.0
TURB	TRBIDMTR	HACH FTU	8	6.125	13.1333	3.624	13.900	2.50
RESIDUE	TOT VOL	MG/L	8	30882.997	8511292.8	2917.412	36200.000	27231.9
RESIDUE	VOL NFLT	MG/L	8	11.000	18.8530	4342	17.000	4.00
SALINITY		0/00	9	17.222	37.2588	6.104	21.500	7.00

NOTE: All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 61

(continued)

1981 SAMPLING DATA

49-A-OYS/OYSTER RIVER
43 07 30 70 52 48
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	142.429	8369.32	91.484	260.000	48.000
FEC COLI	MPN	TUBECODE	6	100.000	2841.63	53.307	160.000	48.000
FEC STRP	MPN-KFBR	TUBECODE	6	105.833	2618.98	51.176	179.000	43.000
BOD	5 DAY	MG/L	8	1.225	0.18749	0.433	2.100	0.800
DO		MG/L	8	9.400	2.036	1.427	12.200	7.500
TKN	N	MG/L	8	0.225	0.0132	0.115	0.320	0.100
NH3+NH4-	N TOTAL	MG/L	8	0.119	0.001	0.036	0.190	0.100
NO2&NO3	N TOTAL	MG/L	8	0.093	0.002	0.046	0.140	0.005
ORTHOPO4	PO4	MG/L	8	0.040	0.008	0.030	0.104	0.002
PHOS-TOT		MG/L P	8	0.061	0.001	0.008	0.077	0.054
LAB	PH	SU	8	7.812	0.018	0.136	8.000	7.500
CONDUCTVY	AT 25C	MICROHMO	8	25487.500	6338693.1	7961.593	34400.000	14000.000
TURB	TRBIDMTR	HACH FTU	8	5.262	6.42116	2.534	9.600	2.[illegible]
RESIDUE	TOT VOL	MG/L	8	23263.374	25159614	5015.936	36900.000	2134.9[illegible]
RESIDUE	VOL NFL	MG/L	8	15.125	381.851	19.541	62.000	1.000
SALINITY		0/00	9	18.833	26.4402	5.142	28.000	11.500

1981 SAMPLING DATA

50-OYS/OYSTER RIVER
43 07 42 70 52 06
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	158.00	4914.71	70.105	260.000	48.000
FEC COLI	MPN	TUBECODE	6	83.333	2530.69	50.306	148.000	48.000
FEC STRP	MPN-KFBR	TUBECODE	6	91.500	2540.66	50.405	160.000	48.000
BOD	5 DAY	MG/L	8	1.487	1.35956	1.166	4.300	0.600
DO		MG/L	8	9.312	1.49573	1.223	11.2	7.500
TKN	N	MG/L	8	0.172	0.00221	0.047	0.260	0.070
NH3+NH4-	N TOTAL	MG/L	8	0.100	0.000	0.000	0.100	0.100
NO2&NO3	N TOTAL	MG/L	8	0.215	0.12960	0.360	1.100	0.050
ORTHOPO4	PO4	MG/L	8	0.027	0.00012	0.011	0.042	0.009
PHOS-TOT		MG/L P	8	0.057	0.00063	0.025	0.119	0.044
LAB	PH	SU	8	7.812	0.01563	0.125	8.000	7.600
CONDUCTVY	AT 25C	MICROMHO	8	27725.000	72735707.4	8531.454	37500.000	15000.000
TURB	TRBIDMTR	HACH FTU	8	3.600	2.9584	1.720	6.600	1.500
RESIDUE	TOT VOL	MG/L	8	32439.873	18578350.0	4304.457	41400.000	26118.984
RESIDUE	VOL NFLT	MG/L	7	28.429	1202.29	34.674	66.000	3.000
SALINITY		0/00	9	19.833	23.1264	4.809	28.500	13.500

NOTE: All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 61

(continued)

1981 SAMPLING DATA

01-OYS/OYSTER RIVER
43 08 00 70 53 06
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	6	128.667	2622.26	51.208	197.000	48.000
FEC COLI	MPN	TUBECODE	6	98.000	2577.59	50.770	148.000	48.000
FEC STRP	MPN-KFBR	TUBECODE	6	105.167	3144.52	56.076	195.000	48.000
BOD	5 DAY	MG/L	8	0.975	0.12532	0.354	1.500	0.300
DO		MG/L	8	9.287	1.50308	1.226	11.500	7.600
TKN	N	MG/L	8	0.261	0.01960	0.140	0.560	0.130
NH3+NH4-	N TOTAL	MG/L	8	0.131	0.00203	0.045	0.190	0.100
NO2&NO3	N TOTAL	MG/L	8	0.091	0.00194	0.044	0.150	0.005
ORTHOPO4	PO4	MG/L	8	0.032	0.00040	0.020	0.045	0.001
PHOS-TOT		MG/L P	8	0.057	0.00010	0.010	0.078	0.043
LAB	PH	SU	8	7.787	0.01277	0.113	7.9	7.6
CONDUCTVY	AT 25C	MICROMHO	8	26712.500	82632681.4	9090.252	38000.00	14000.00
TURB	TRBIDMTR	HACH FTU	8	5.600	9.25376	3.042	10.800	1.900
RESIDUE	TOT VOL	MG/L	8	30370.874	28767486.2	5363.533	38900.00	22605.99
RESIDUE	VOL NFLT	MG/L	8	8.875	8.41000	2.900	14.000	5.000
SALINITY		0/00	9	18.667	24.2458	4.924	27.500	12.500

1981 SAMPLING DATA

49-OYS/OYSTER RIVER
43 07 48 70 53 00
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	160.286	11292.2	106.265	336.000	48.000
FEC COLI	MPN	TUBECODE	6	97.000	3116.43	55.825	118.000	48.000
FEC STRP	MPN-KFBR	TUBECODE	6	99.500	3879.92	62.289	178.000	48.000
BOD	5 DAY	MG/L	8	1.200	0.10890	0.330	1.900	0.800
DO		MG/L	8	9.337	1.34792	1.161	11.100	7.500
TKN	N	MG/L	8	0.197	0.00578	0.076	0.310	0.110
NH3+NH4-	N TOTAL	MG/L	7	0.101	0.00002	0.004	0.110	0.100
NO2&NO3	N TOTAL	MG/L	8	0.087	0.00130	0.036	0.140	0.050
ORTHOPO4	PO4	MG/L	8	0.028	0.00017	0.013	0.042	0.001
PHOS-TOT		MG/L P	8	0.049	0.00010	0.010	0.066	0.033
LAB	PH	SU	8	7.812	0.01563	0.125	8.000	7.600
CONDUCTVY	AT 25C	MICROMHO	8	26512.500	70329826.4	8386.288	38000.000	.4000000
TURB	TRBIDMTR	HACH FTU	8	4.662	4.58816	2.142	8.800	2.000
RESIDUE	TOT VOL	MG/L	8	33867.498	58287361.5	7634.616	49700.000	25470.990
RESIDUE	VOL NFLT	MG/L	8	15.500	422.590	20.557	65.000	2.000
SALINITY		0/00	9	19.222	23.0112	4.797	27.500	12.500

NOTE: All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 61

(continued)

1981 SAMPLING DATA

47-A-OYS/OYSTER RIVER
43 08 00 70 54 42
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	325.429	5542.36	74.447	463.000	235.00
FEC COLI	MPN	TUBECODE	7	249.571	6938.89	83.300	336.00	118.00
FEC STRP	MPN-KFBR	TUBECODE	6	169.167	1951.34	44.174	238.000	113.000
BOD	5 DAY	MG/L	8	1.252	0.17389	0.417	1.900	0.800
DO		MG/L	8	9.150	1.91546	1.384	11.400	7.300
TKN	N	MG/L	8	0.452	0.06250	0.250	0.820	0.160
NH3+NH4-	N TOTAL	MG/L	8	0.205	0.01020	0.101	0.340	0.100
NO2&NO3	N TOTAL	MG/L	8	0.171	0.00828	0.091	0.340	0.060
ORTHOPO4	PO4	MG/L	8	0.061	0.00116	0.034	0.103	0.017
PHOS-TOT		MG/L P	8	0.103	0.00102	0.032	0.140	0.045
LAB	PH	SU	8	7.300	0.06300	0.251	7.600	6.000
CONDUCTVY	AT 25C	MICROMHO	8	21700.00	69362862.9	8328.437	34000.00	10000.00
TURB	TRBIDMTR	HACH FTU	8	9.212	19.2633	4.389	18.100	4.100
RESIDUE	TOT VOL	MG/L	8	19734.624	79693917.9	8927.145	28500.00	565[illegible]
RESIDUE	VOL NFLT	MG/L	8	12.750	60.7932	7.797	25.000	1.000
SALINITY		0/00	9	14.444	32.5927	5.709	24.000	4.000

1981 SAMPLING DATA

47-OYS/OYSTER RIVER
43 08 00 70 54 42
OYSTER RIVER ESTUARY
33017 NEW HAMPSHIRE STRAFFORD
NORTH ATLANTIC 021000
PISCATAQUA RIVER AND NEW HAMPSHIRE COAST
22NHCITY

PARAMETER			NUMBER	MEAN	VARIANCE	STAN DEV	MAXIMUM	MINIMUM
TOT COLI	MPN CONF	TUBECODE	7	326.143	5009.53	70.778	436.000	236.00
FEC COLI	MPN	TUBECODE	7	258.429	4684.58	68.444	336.000	136.00
FEC STRP	MPN-KFBR	TUBECODE	7	184.143	3131.52	55.960	266.000	130.00
BOD	5 DAY	MG/L	8	1.962	0.70896	0.842	3.200	0.70
DO		MG/L	8	9.112	1.81710	1.348	11.200	7.00
TKN	N	MG/L	8	0.517	0.09610	0.310	1.100	0.10
NH3+NH4-	N TOTAL	MG/L	8	0.296	0.08585	0.293	0.920	0.10
NO2&NO3	N TOTAL	MG/L	8	0.157	0.00518	0.072	0.220	0.06
ORTHOPO4	PO4	MG/L	8	0.052	0.00116	0.034	0.113	0.00
PHOS-TOT		MG/L P	8	0.114	0.00040	0.020	0.158	0.09
LAB	PH	SU	8	7.425	0.05664	0.238	7.600	6.900
CONDUCTVY	AT 25C	MICROMHO	8	22425.000	76002146.6	8717.921	36000.00	10000.00
TURB	TRBIDMTR	HACH FTU	8	8.537	18.4127	4.291	18.000	4.600
RESIDUE	TOT VOL	MG/L	8	24118.374	82262160.9	9069.849	41800.00	13129.99
RESIDUE	VOL NFLT	MG/L	8	10.000	28.0053	5.292	19.000	1.000
SALINITY		0/00	9	14.722	46.0091	6.783	24.500	3.00

NOTE: All bacteriological data are expressed as Log_{10} (MPN/100 ml sample) x 100

TABLE 62

Storms of July 13 - 15, 1981
Data for Model Simulation

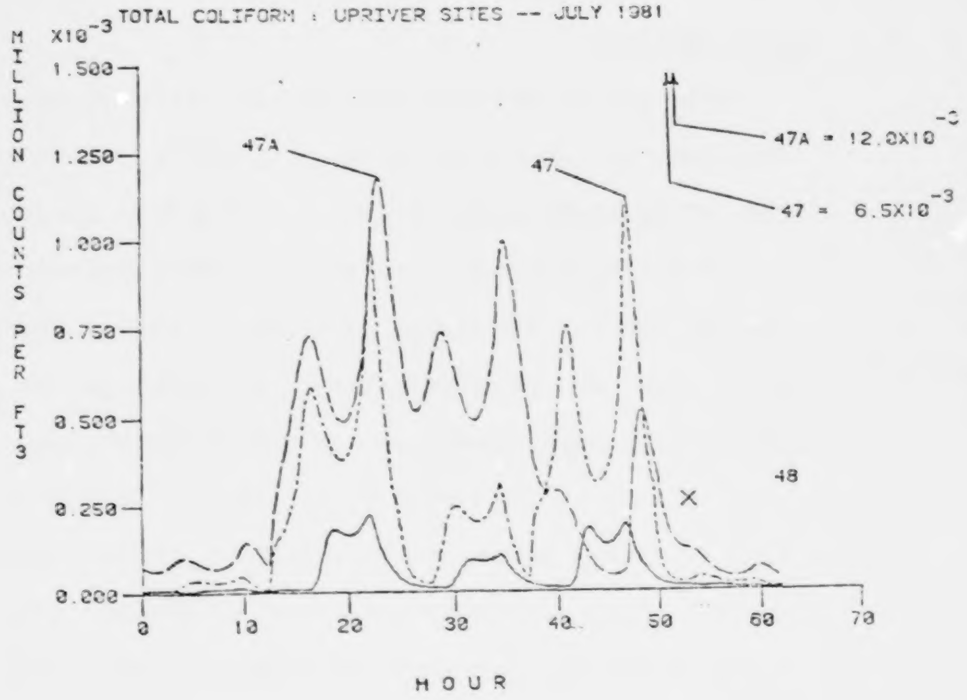
		Tidal Cycle				
	Station	1	2	3	4	5
Flow Rate	5-Oys	20.5	23.0	23.0	17.2	17.2
(cfs)	2-Pte.	1.0	2.7	1.0	2.05	1.0
	WWTF	0.225	0.225	0.225	0.225	0.225
Total Coliform	5-Oys	6.23 E-04	3.96 E-03	3.96 E-03	3.40 E-04	3.40 E-04
Concentration	2-Pte	7.65 E-04	3.96 E-02	7.65 E-04	7.93 E-02	7.65 E-04
(Million cts/cf)	WWTF	2.04 E-05	2.04 E-05	2.04 E-05	2.04 E-05	2.04 E-05
	50-Oys	1.42 E-05	1.42 E-05	1.42 E-05	1.42 E-05	2.55 E-05
Fecal Coliform	5-Oys	5.66 E-05	7.65 E-04	7.65 E-04	2.27 E-05	2.27 E-05
Concentration	2-Pte	4.81 E-05	6.51 E-04	4.81 E-05	1.42 E-03	4.81 E-05
(Million cts/cf)	WWTF	1.98 E-06	1.98 E-06	1.98 E-06	1.98 E-06	1.98 E-06
	50 Oys	1.42 E-06	1.42 E-06	1.42 E-06	1.42 E-06	1.42 E-06
BOD Concentration	5-Oys	1.62 E-04	2.50 E-04	2.50 E-04	2.00 E-04	2.00 E-04
(lbs/cf)	2-Pte	1.00 E-04	4.37 E-04	1.00 E-04	8.68 E-04	1.00 E-04
	WWTF	4.06 E-04	4.06 E-04	4.06 E-04	4.06 E-04	4.06 E-04
	50 Oys	1.25 E-04	1.25 E-04	1.25 E-04	1.25 E-04	6.87 E-05
Dissolved Oxygen	5-Oys	5.31 E-04	5.31 E-04	5.31 E-04	5.31 E-04	5.31 E-04
Concentration	2-Pte	5.31 E-04	5.31 E-04	5.31 E-04	5.31 E-04	5.31 E-04
(lbs/cf)	WWTF	3.12 E-04	3.12 E-04	3.12 E-04	3.12 E-04	3.12 E-04
	50 Oys	5.37 E-04	5.37 E-04	5.37 E-04	5.37 E-04	5.37 E-04

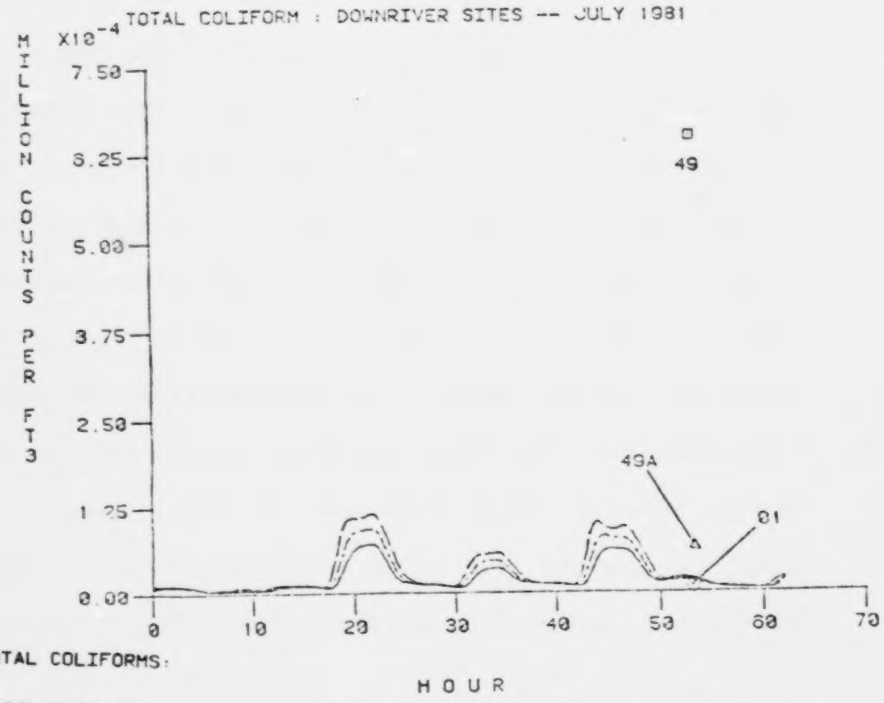
Total Coliform

Model predictions were made for total coliform concentration using a decay rate of 1.85/day (after Mancini, 1981). Predictions for concentration in the river channel are given in Figure 26 for the downriver and upriver sampling stations. The downriver plots show a rather simple and expected harmonic oscillation of coliform counts. Concentrations increase at low tide, when dilution effects from seaward-derived water are at a minimum, and decrease when more dilute floodwaters enter the study site. (See Table 63 for the timing of the tides.) Compared to field-measured data, reasonable agreement with simulation results occurs only at sites 01 and 49A. The disparity is substantial at site 49. Site 48 behaves essentially as did the three downriver sites, but the picture at sites 47 and 47A is far more complicated. As a consequence of their proximity to the freshwater loading, sites 47 and 47A experience elevated coliform concentration during both flood and ebb tides. In addition, there is an interesting double peak which accompanies each tidal cycle whereby each flooding or ebbing period has an associated concentration peak. The system's behavior is counter-intuitive, for we expect that dilution by incoming ocean water will always decrease constituent concentration upriver.

How might this be explained? Starting at dead low tide, with a minimum of water volume into which the loading can be diluted, the two sites will undergo a peak in constituent concentration in response to the elevated stormwater loading. However, the concentration must eventually be diminished when the tides flood inward and seaward dilution becomes prominent, thereby reducing concentration substantially. However, before the tide peaks, the movement of dilution water into the upriver channel sites slows and the continual loading can elevate the coliform concentration. At some

FIGURE 26


TOTAL COLIFORM : UPRIVER SITES -- JULY 1981


TOTAL COLIFORM : DOWNRIVER SITES -- JULY 1981

FOR TOTAL COLIFORMS:

VIOLATION ABOVE
2.0E-05

TABLE 63

OYSTER RIVER SIMULATION
JULY RUN

TIMING OF FLOOD AND EBB TIDES

FLOODING TIDES	EBBING TIDES
0.0 - 3.1 hrs	3.1 - 9.3 hrs
9.3 - 15.5	15.5 - 21.7
21.7 - 27.9	27.9 - 34.1
34.1 - 40.3	40.3 - 46.5
46.5 - 52.7	52.7 - 58.9
58.9 - 62.0	

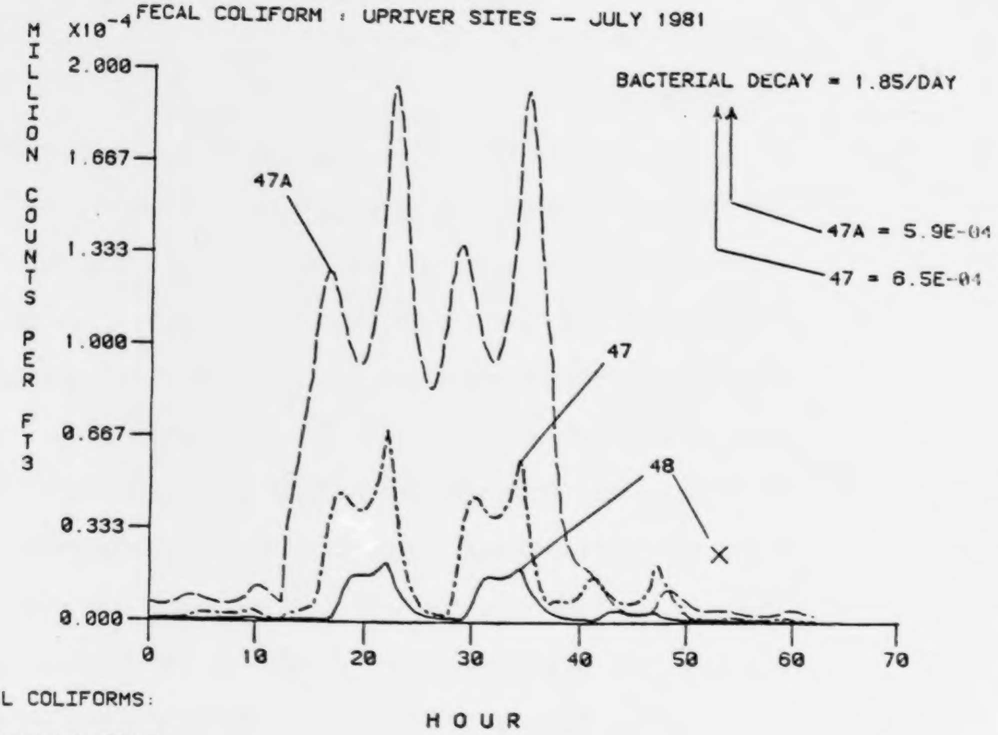
point, it becomes slack high tide, and soon thereafter water which has resided on the mudflat begins to dilute the channel concentration as the tide falls, now overriding the effect of upriver loading. The reason this lateral water is a relatively good "diluter"involves its relatively large volume and the fact that increased residence time of water over the mudflats lengthens the period in which decay processes will operate. Only after mid-ebb is the influence of this dilution water overridden by the freshwater loading effects. These interesting dynamics point to the inherent complexity of such ecosystems and argue for cautious statements regarding the quantitative aspects of estuarine water quality.

Nonetheless, we can see that in the upriver sections of the Oyster River, there will likely be quite severe coliform standard violations during storm events similar to those simulated. In addition, loading from the rather modestly-sized Pettee Brook is quite important to monitor during such storms as evidenced by its effects on upriver water quality between hours 38 and 50, a time when the influence of the Oyster River influent was diminished. As a final note, there is rather poor agreement between observed and predicted concentrations at all three upriver sites.

Fecal Coliform

Fecal coliform predictions are displayed in Figure 27. The same type of qualitative behavior exists for both the upriver and downriver sites as had existed in the total coliform run. As before, the quantitative correspondence between model prediction and empirical measurement is rather tenuous. However, according to the analysis, there will be substantial water quality violations (>0.4E-05 million counts per cubic foot) throughout much of the estuary during storm events. Except for site 47A, where violations exist for the full duration of the storms, all other sites

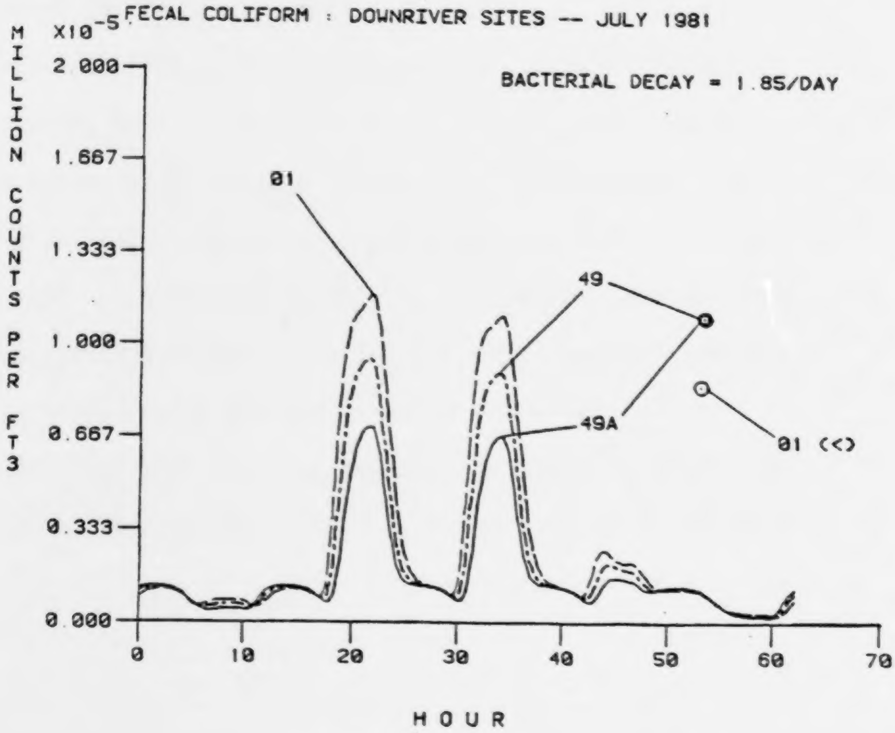
FIGURE 27



FOR FECAL COLIFORMS:

VIOLATION ABOVE

4.0E-08



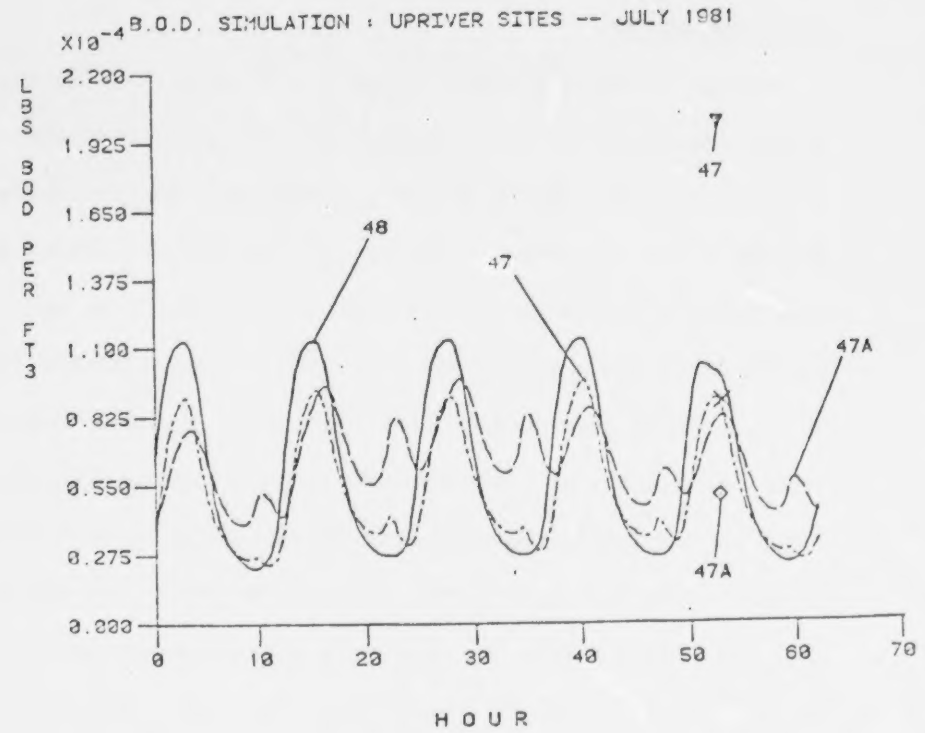
violate regulations during ebb tides. During flood tides, seaward dilution spares violation.

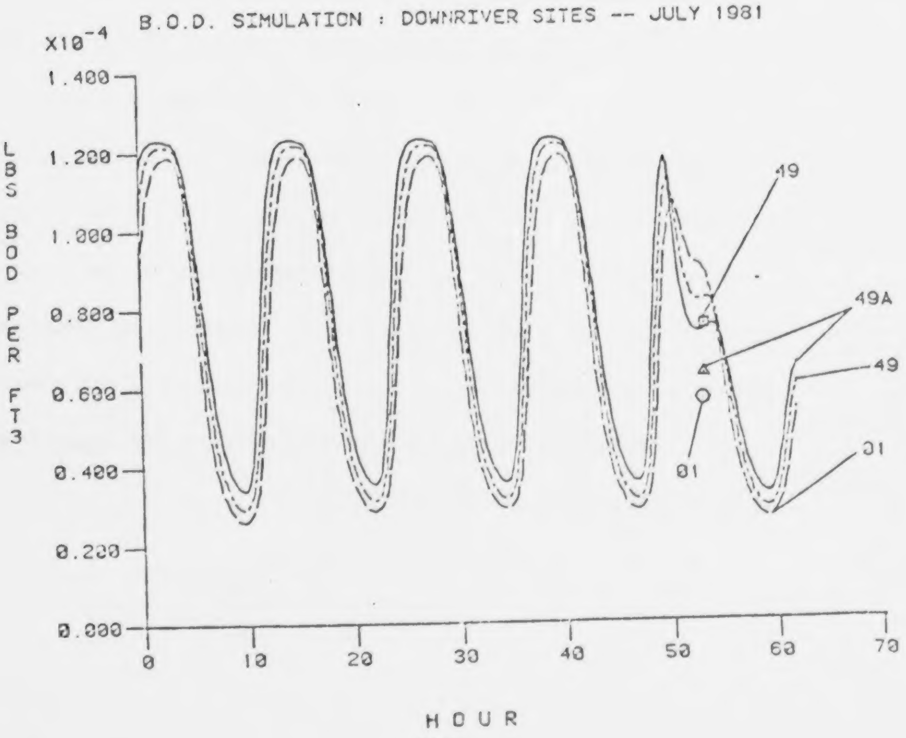
BOD Analysis

In the BOD simulations we have the best agreement with field data. The BOD curves displayed in Figure 28 show a strong cyclic pattern which is contrary to our expectation that on flooding tides dilution by incoming seawater will depress constituent concentration. We see just the opposite effect--on ebbing tides there is a decrease in oxygen demand. The predominant determinant of this effect is biotic processing. Material is loaded into the system from both the upriver and ocean boundaries, but the bulk is added during floodwater tides downriver. Despite this, we can observe an inverted position of concentration plots among the downriver study sites, with the most seaward position tabulating the highest concentrations. This argues that organic material within the estuary has undergone biological transformation. Furthermore, the effect of decay can also be observed at the upriver sites, those areas that have spent the longest time experiencing decay. Upriver, concentrations are significantly lower than in the downriver sites, despite their proximity to high point source concentrations. Furthermore, in plots of passively distributed BOD (not shown), there is significant dampening of timeseries oscillations centered about 1.25E-04 lbs. BOD per ft3 throughout the estuary. The periodicity is therefore predominantly a function of biotic activity and not dilution.

Finally, the irregularity at the end of the storm sequence represents the effect of changing the ocean boundary loading. Therefore, from the BOD analysis it is easy to recognize the influence of the biota and the importance of the seaward boundary.

FIGURE 28


B.O.D. SIMULATION : UPRIVER SITES -- JULY 1981
X10⁻⁴
LBS BOD PER FT3
2.200
1.925
1.650
1.375
1.100
0.825
0.550
0.275
0.000
0
10
20
30
40
50
60
70
HOUR
48
47
47A
47
47A

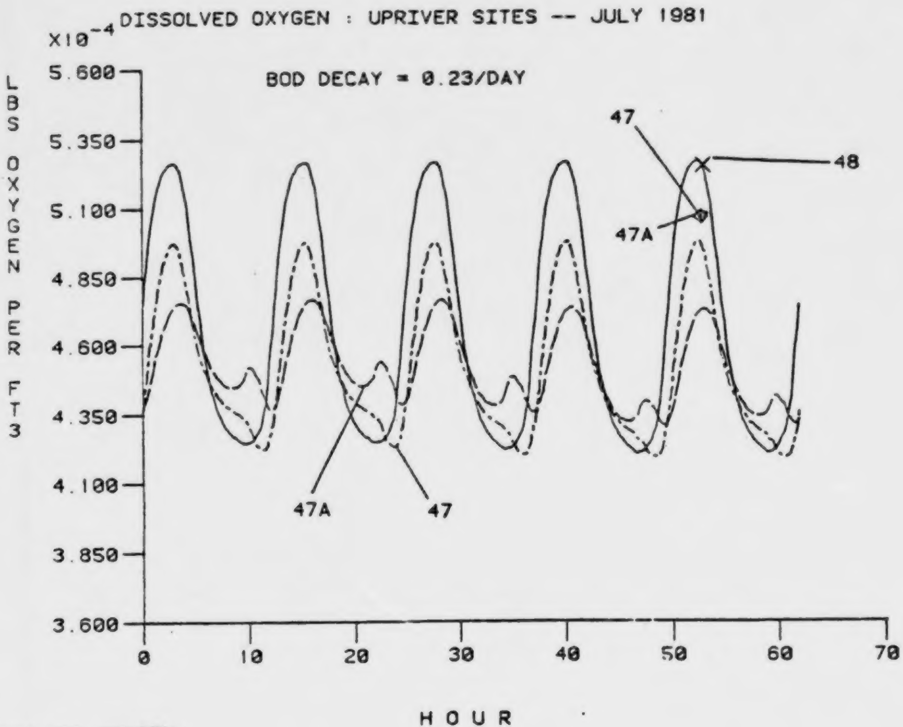

B.O.D. SIMULATION : DOWNRIVER SITES -- JULY 1981
X10⁻⁴
LBS BOD PER FT3
1.400
1.200
1.000
0.800
0.600
0.400
0.200
0.000
0
10
20
30
40
50
60
70
HOUR
49
49A
49
01
01

Dissolved Oxygen

Linked to the BOD analysis was a consideration of dissolved oxygen. Oxygen concentration was distributed by physical transport and simultaneously diminished by an amount corresponding to the exerted biochemical demands. For each model timestep, it then was readjusted by oxygen diffusion using a reaeration coefficient of 0.27/day. The qualitative behavior of the dissolved oxygen predictions (Figure 29) mimicked the BOD timeseries, for as oxygen demand was exerted it depressed oxygen concentration. Thus, the oscillations were synchronized to BOD exertion, and, in fact, for each site reported, the DO amplitudes were virtually identical to those for the BOD predictions. Again, the effect of biotic activity is apparent. As for BOD, the agreement with measured data is substantially better for the dissolved oxygen simulation when compared to the coliform runs. For sites 49, 01, 47, and 48, predictions are virtually identical to field observations. It appears that the entire estuarine system is above the 6 mg/l criteria for DO in natural waters. On the scales prsented in our graphs, violations would occur below 3.7E-04 lbs per ft^3 (=6 mg/l).

As a test of the importance of the seaward boundary as discerned from the BOD analysis, we varied the seaward concentration downward to 8.0 mg/l (or 4.9E-04 lbs/ft3) and obtained the plots shown in Figure 30. Not only is the mean concentration significantly depressed, but the amplitude of the oscillations is diminished as well. Again, the importance of the downriver boundary is demonstrated. Detailed timeseries information during incoming tides is therefore critical in determining the quantitative behavior of constituents within the estuary.

FIGURE 29


DISSOLVED OXYGEN : UPRIVER SITES -- JULY 1981

FOR DISSOLVED OXYGEN:

VIOLATION BELOW

4.1E-04

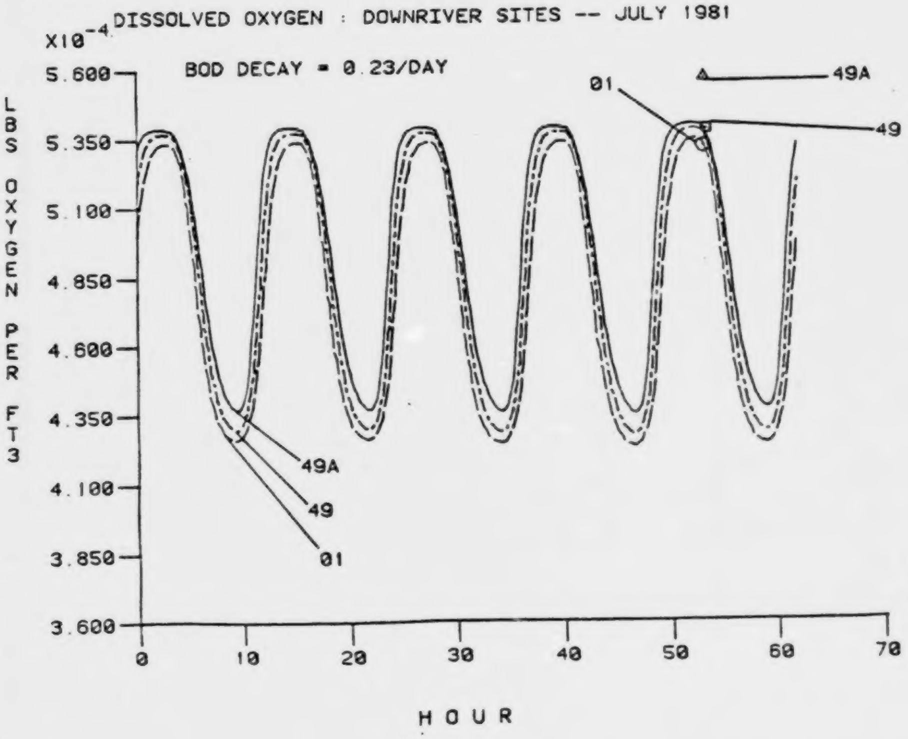
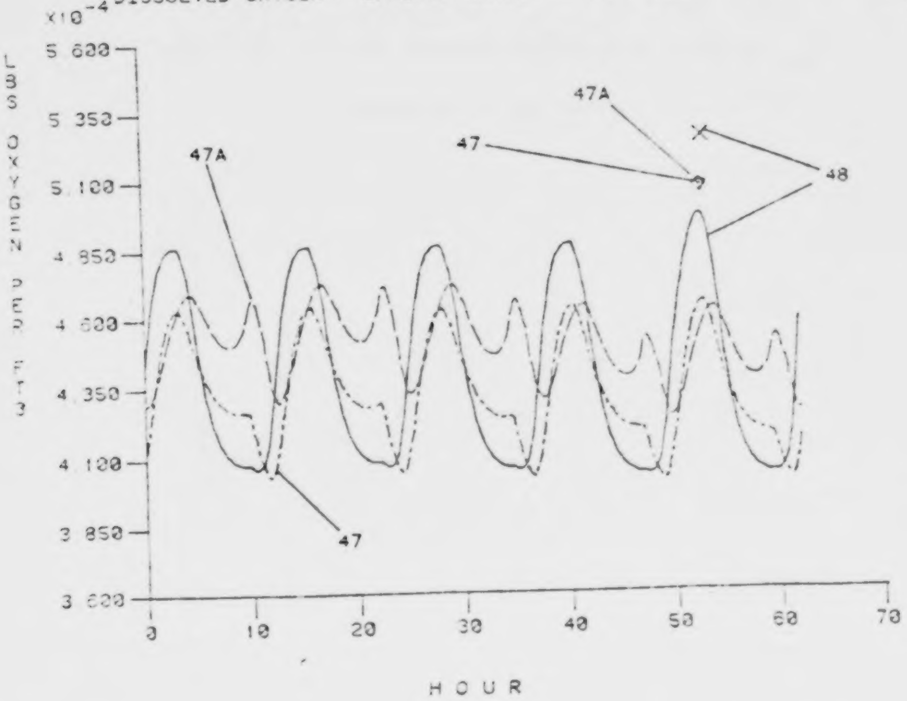
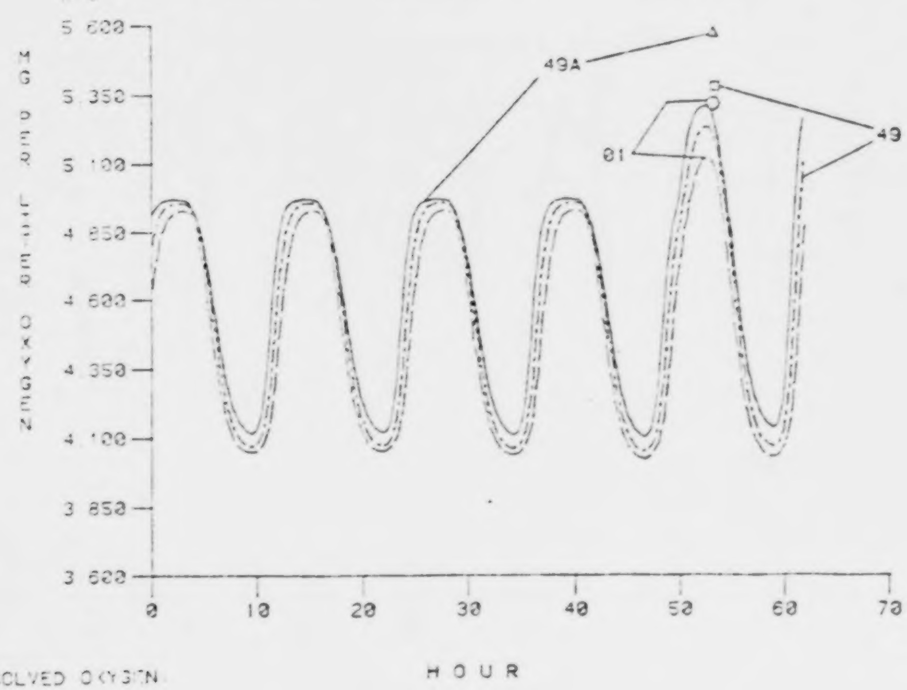

DISSOLVED OXYGEN : DOWNRIVER SITES -- JULY 1981

FIGURE 30

DISSOLVED OXYGEN : UPRIVER SITES -- JULY 1981



DISSOLVED OXYGEN : DOWNRIVER SITES -- JULY 1981



FOR DISSOLVED OXYGEN

VIOLATION BELOW

4.1E-04

Summary

Results of the model verification exercise show poor quantitative agreement between observed and predicted coliform concentrations, particularly at the upriver sites. Primarily, these discrepancies result from unsatisfied data requirements of the model. Intensive timeseries data become extremely important when attempting to simulate constituents such as coliforms where extreme concentration variability is inherent. However, although coliform concentration changes are not reasonably predicted in terms of magnitude, trends of longitudinal change in the estuary which reflect general dynamics are in agreement.

It should also be noted that although significant disparity exists between model simulated results and actual field conditions, the differences do not necessarily imply that either the model or field data are fundamentally incorrect. Schmidt (1981) found vertical stratification of the Oyster River Estuary to be significant, especially in determining the dispersive properties of mass transport in the system. Our model reports net cross-sectionally averaged flux of material. Field samples were collected in near-surface waters, which may have shown significant differences with vertically composited samples.

Results for BOD and dissolved oxygen simulations do result in reasonable agreement with observed conditions. Since BOD concentration changes do not exhibit the extreme variability observed with the coliforms, the lack of intensive timeseries data becomes less critical in terms of quantitative agreement between observed and predicted results.

In essence, results of the July simulations reveal the importance of adequate data inputs for concise quantitative modeling; however, even without these data, general estuary dynamics of biotic and hydrodynamic influences on stormwater pollutant loads can be simulated effectively using the detailed numerical model.

III.4 PROJECTED STORM RUNOFF LOADING ANALYSIS

On the basis of extensive stormwater runoff and quality monitoring at the 5-Oys and 2-Pte locations, statistical probabilities of storm loading rates have been computed. For the purpose of this analysis sustained stormwater loading of total and fecal coliforms at the 90th, 50th, and 10th percentile have been modeled to estimate impacts in the estuary. Statistically speaking, 90th percentile, for example, signifies that 90 percent of all storms will convey less coliform loading. Results of this analysis are intended to provide insight into the frequency and longitudinal magnitude of dissolved oxygen and coliform bacteria violations resulting from stormwater loading to the estuary.

The coliform loading rates are offered in Table 64. Since the estuary did not experience oxygen deficit problems, it was instructive to attempt to establish the approximate BOD influx which would cause water standards violations. The BOD loading rates attempted were merely multiples of the July 1981 base flow loading upriver as given in Table 62.

Except for the upriver inputs, forcing functions were identical to those of the first cycle in our multiple storm event analysis for July 1981. This included the bacterial decay rate of 1.85/day. Again, it must be emphasized that we had difficulty in realizing quantitative correspondence among field measurements and model predictions. Therefore, the results derived below must be viewed as qualitative and indicative of general patterns.

TABLE 64

COLIFORM BACTERIA LOADING PROBABILITIES

Stormwater Loading

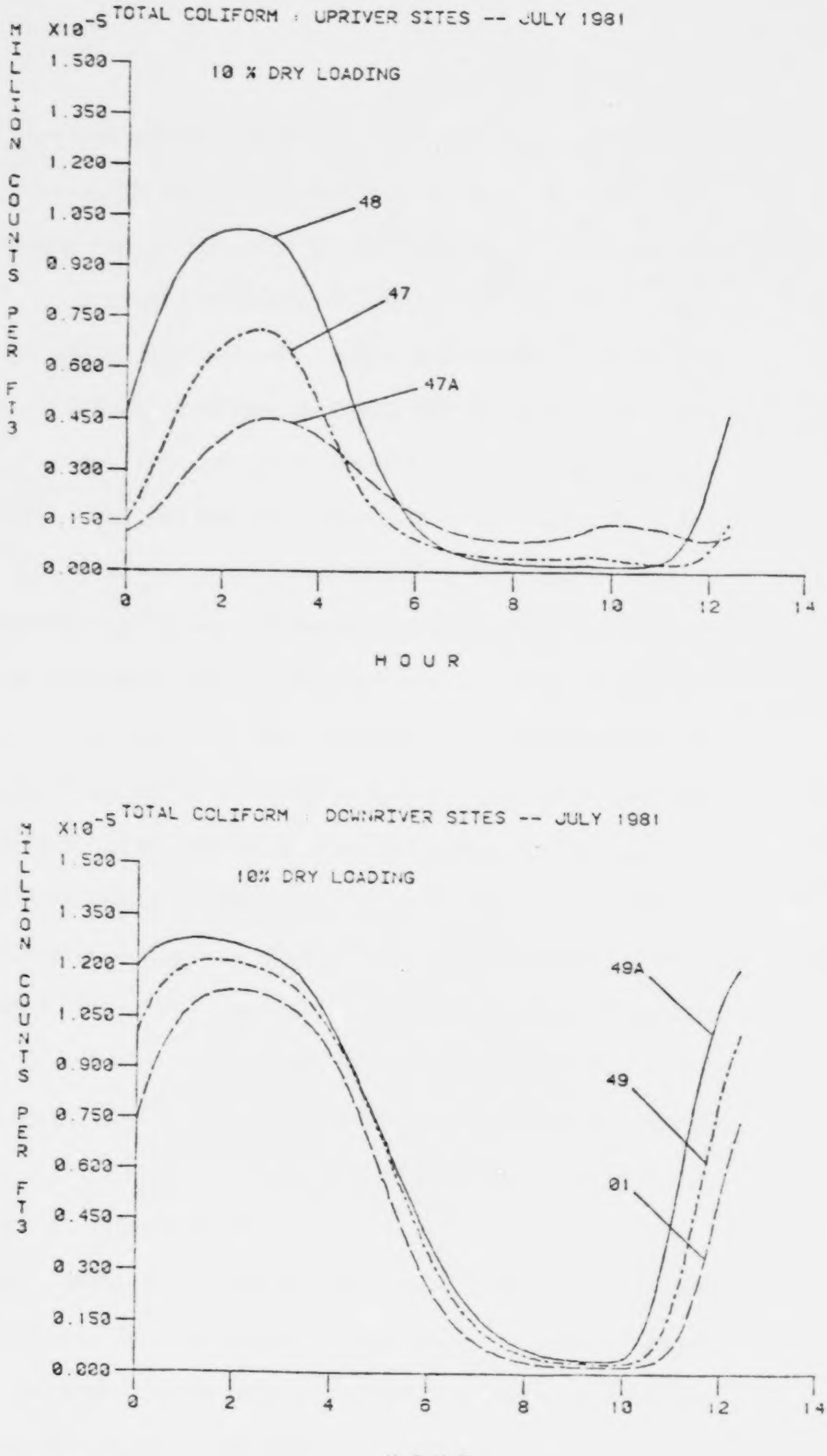
	Total Coliform	Fecal Coliform	Flow Rate
5-Oys		(Million counts/cubic foot)	
90th	2.55 E-02	9.90 E-04	63.7
50th	3.12 E-03	1.70 E-04	33.3
10th	3.96 E-04	2.83 E-05	22.3
2-Pte			
90th	7.08 E-02	6.23 E-03	4.20
50th	2.01 E-02	9.10 E-04	1.40
10th	4.25 E-03	1.33 E-04	0.50
		Dry Weather Loading	
5-Oys			
90th	6.51 E-04	3.40 E-05	43.0
50th	1.13 E-04	6.80 E-06	20.0
10th	1.92 E-05	1.42 E-06	6.0
2-Pte			
90th	2.72 E-03	1.76 E-03	0.83
50th	5.38 E-04	4.53 E-05	0.49
10th	1.02 E-04	1.20 E-05	0.07

Total Coliform Bacteria

Results from the total coliform loading analysis are given in Figures 31 through 36. Let us consider first the dry weather loading runs. For 10% dry loading we see that in both the up and downriver sites the influence of the upriver inputs is minimal (Figure 31). The concentration at any point is determined almost exclusively by the seaward boundary inputs. Thus, at high tide the sampling stations experience elevated coliform concentrations, while during ebb flow they fall to near zero. No violations (>2.0E-05 MCF$_3$) were recorded. In the 50% dry loading (Figure 32), there is more freshwater infuence and this shows up in the 'double peak behavior' for the upriver sites, a phenomenon described earlier. Since the upriver loading is still relatively modest, the downriver sites behaved much like in the previous run. However, the site just downriver of the Oyster River dam tabulates sustained exceedence of total coliform standards. However, no other sites appear to have suffered similar difficulties. In the 90% loading scenario, concentrations are extremely high to the point that only during flooding tides do all three upriver stations fall within conformance standards (Figure 33). The downriver sites also begin to experience the effect of the upriver system components, and during ebb stage concentrations rise sharply. Concentrations at site 01 approach levels which are indicative of violations.

A similar progression of upriver influence is to be expected in the stormwater loading scenarios for total coliforms. However, at the 10% storm loading level we see in Figure 34 that site 47, and as well site 47a, experience long-term standard violations. Downriver there is no exceedence of the 2.0E-05 MCF^3 standard, but there is an interesting hint of freshwater influence during the ebb tide at all downriver stations between hours

FIGURE 31



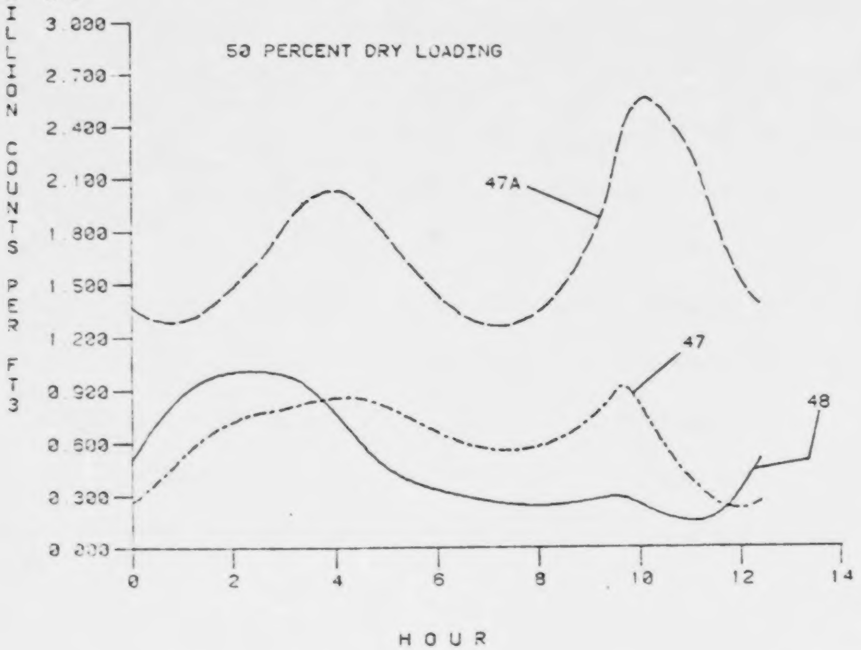
FOR TOTAL COLIFORMS

VIOLATION ABOVE

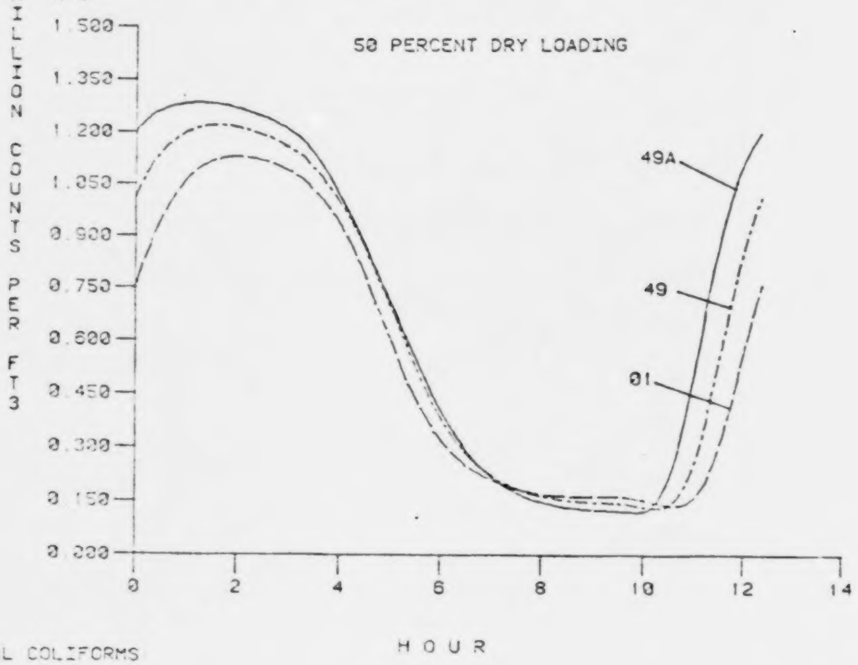
2.0E-05

FIGURE 32

TOTAL COLIFORM : UPRIVER SITES -- JULY 1981



TOTAL COLIFORM : DOWNRIVER SITES -- JULY 1981



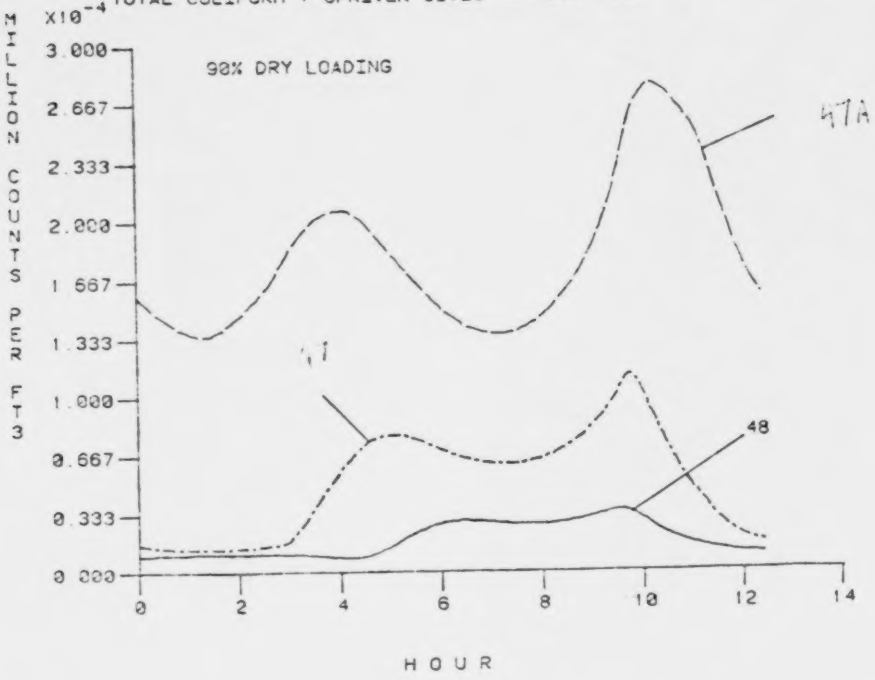
FOR TOTAL COLIFORMS

VIOLATION ABOVE

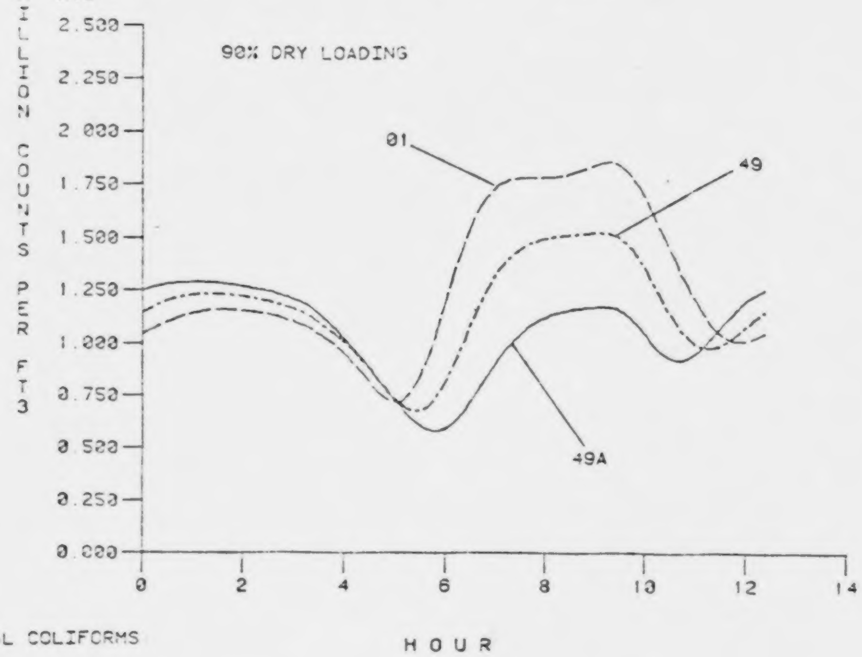
2.0E-05

FIGURE 33

TOTAL COLIFORM : UPRIVER SITES -- JULY 1981



TOTAL COLIFORM : DOWNRIVER SITES -- JULY 1981

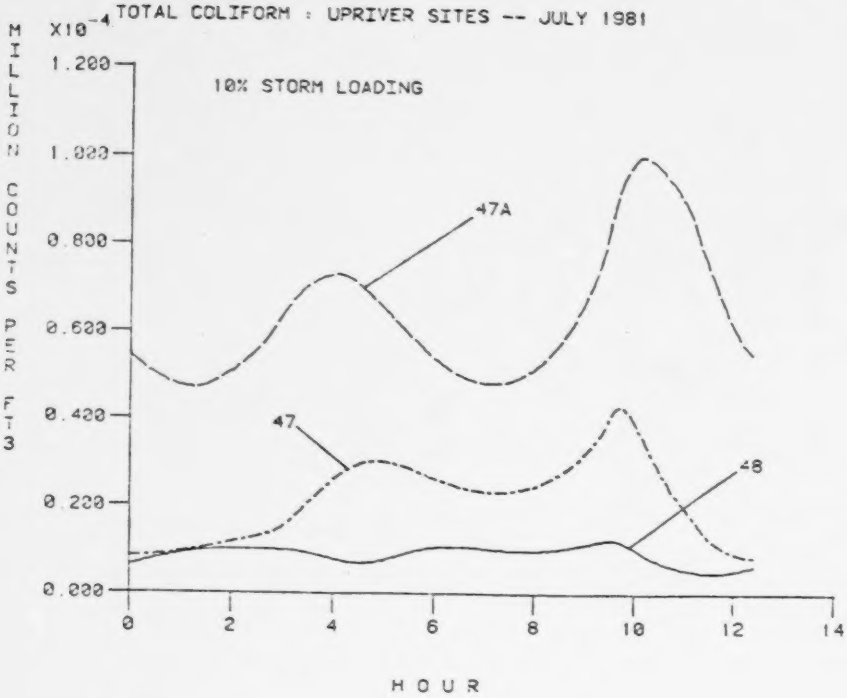


FOR TOTAL COLIFORMS

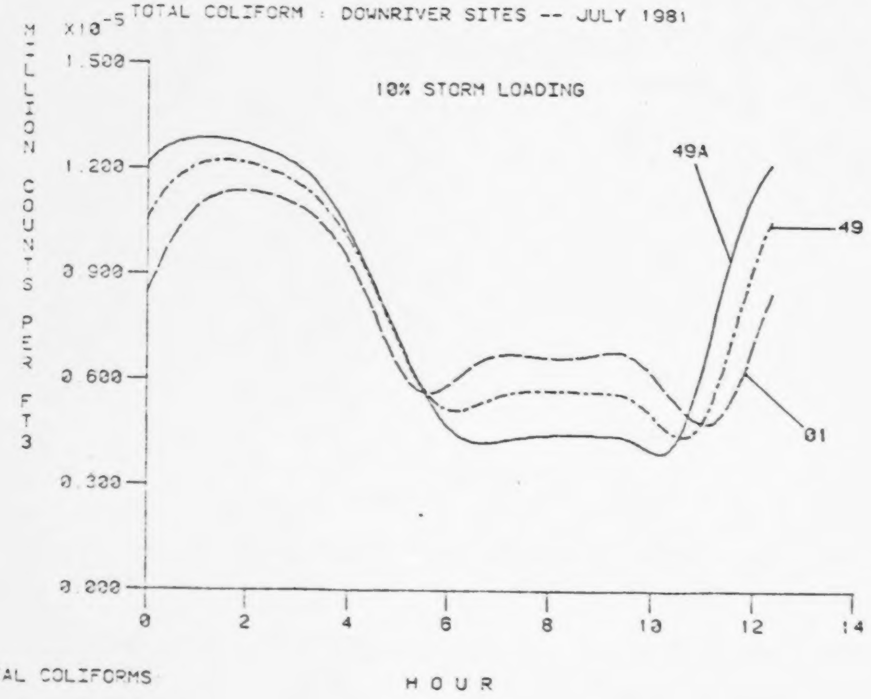
VIOLATION ABOVE

2.0E-05

FIGURE 34



TOTAL COLIFORM : UPRIVER SITES -- JULY 1981



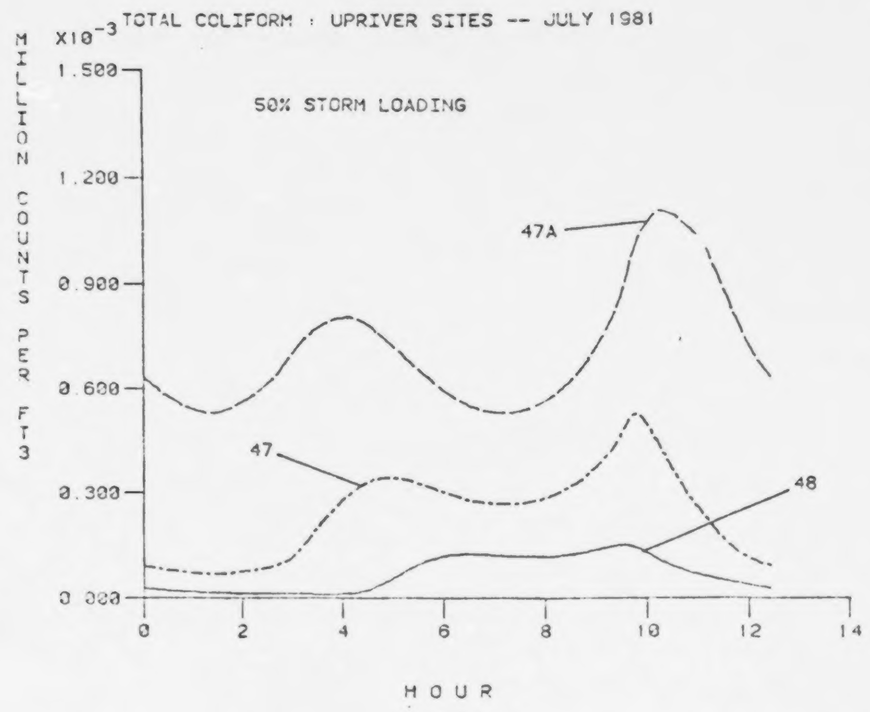
TOTAL COLIFORM : DOWNRIVER SITES -- JULY 1981

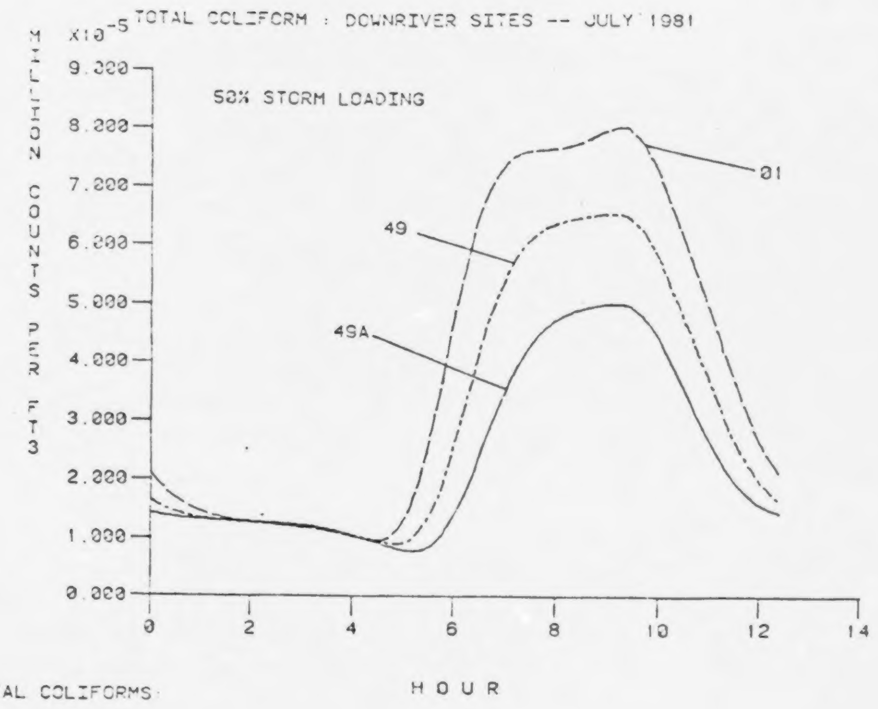
FOR TOTAL COLIFORMS

VIOLATION ABOVE

2.0E-05

FIGURE 35



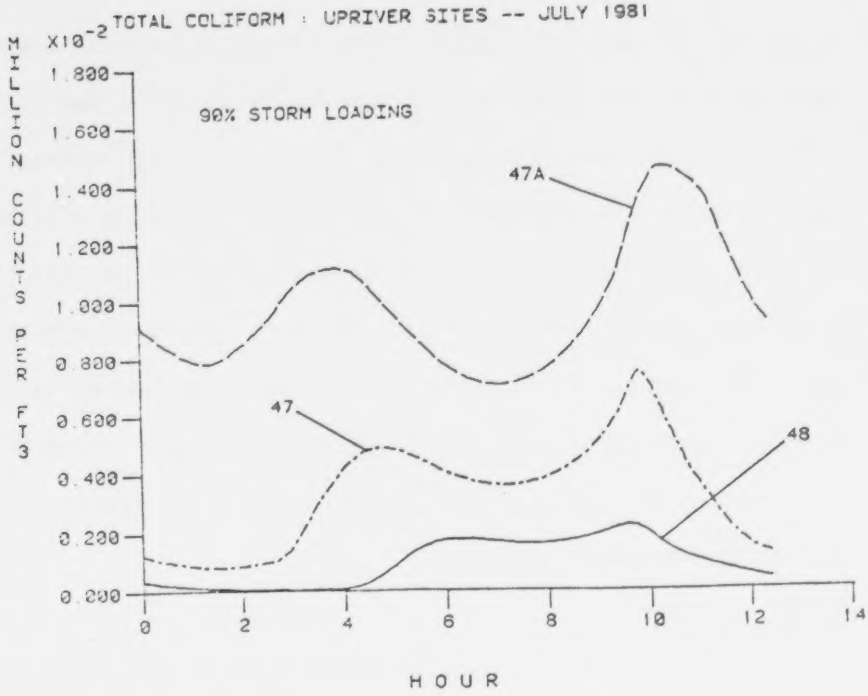


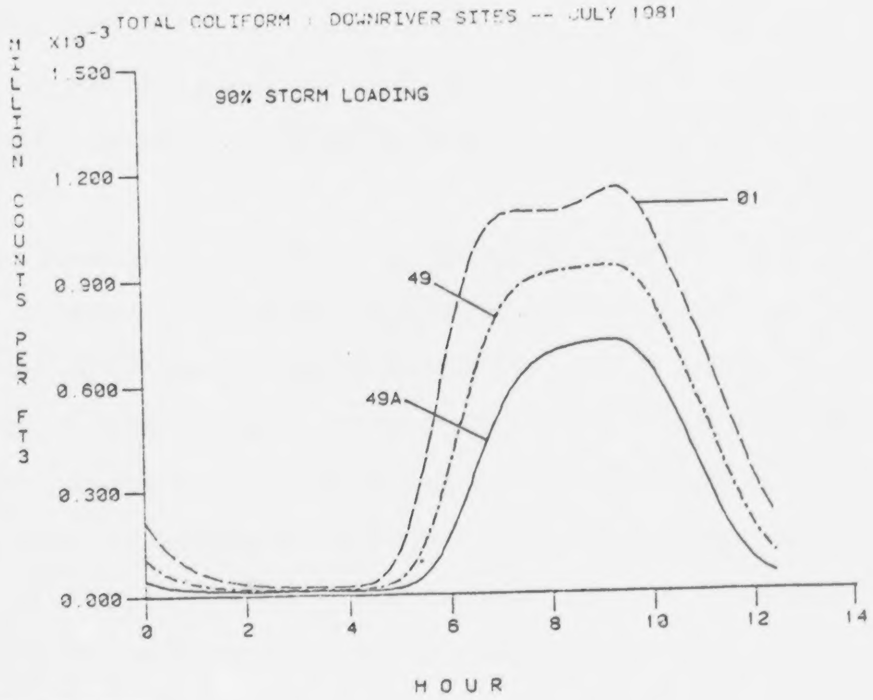
FOR TOTAL COLIFORMS

VIOLATION ABOVE

2.0E-05

FIGURE 36


TOTAL COLIFORM : UPRIVER SITES -- JULY 1981


TOTAL COLIFORM : DOWNRIVER SITES -- JULY 1981

FOR TOTAL COLIFORMS

VIOLATION ABOVE

2.0E-05

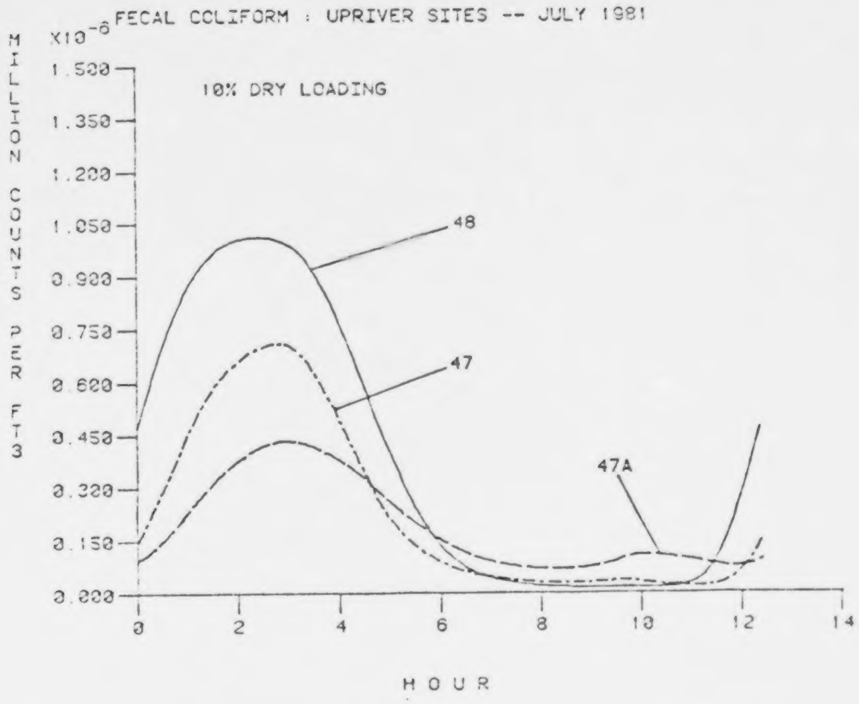
6 and 10. As we might expect, this ebb-stage increase downriver will amplify with increased loading, and in Figure 35 we see a dramatic rise, far above water quality standards for all downriver sites, when 50% storm loading rates are applied. Of course, the situation will be quite severe upriver, and violations are tabulated at sites 47 and 47A that are over 10 times the legal limit. Carrying the analysis one step further, we see the expected, sustained violation of both downriver and upriver sites with 90% loading (see Figure 36). The downriver sites now exceed coliform standards by a factor of 10 except during high tides. The upriver sites at ebb flow exceed standards by 100-fold.

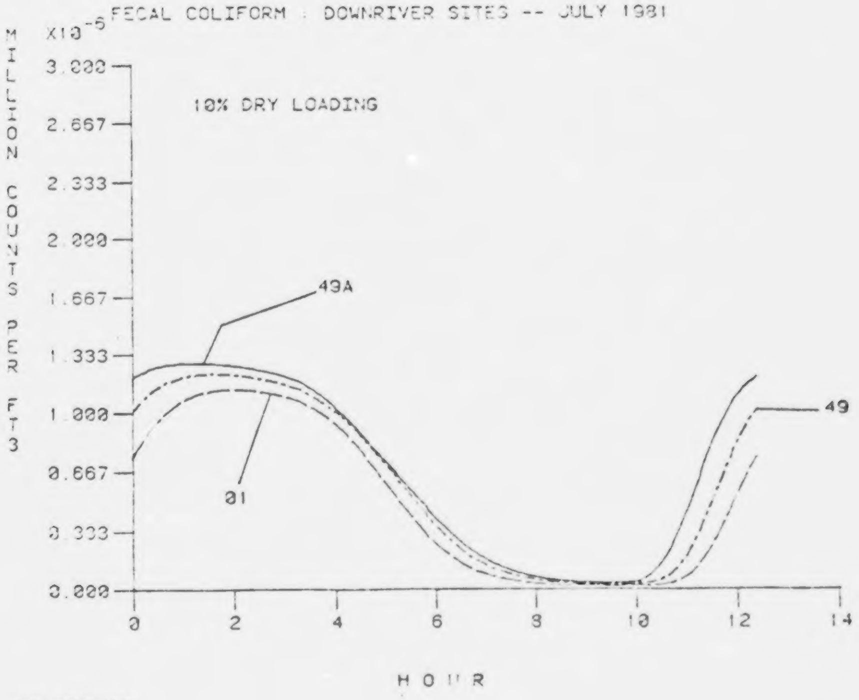
Fecal Coliform

The results for the fecal coliform loading scenarios are graphically displayed in Figures 37 through 42. Let us consider the dry loading first. Similar to the total coliform loading analysis, increased freshwater loading begins to propagate its effect downriver. This time, however, it fails to produce fecal coliform violations (>4.0E-06 MCF^3) except in the upriver reaches during 90% dry loading (compare Figures 37 through 39).

The following statements can be made of our hypothetical system at storm loading: at the 90 percent loading rate, violations are severe, approaching 10 times the allowable limits, even in the downriver portions of the estuary when tides are ebbing. The situation is far worse upriver, and at sites 47 and 47A concentrations are approximately two orders of magnitude higher than legal standards throughout the storm cycle. For 50th percentile loading, there are less severe effects, but the upriver sites tally violations about an order of magnitude above the allowable limit throughout the tidal cycle. There are still ebb-tide violations downriver,

FIGURE 37



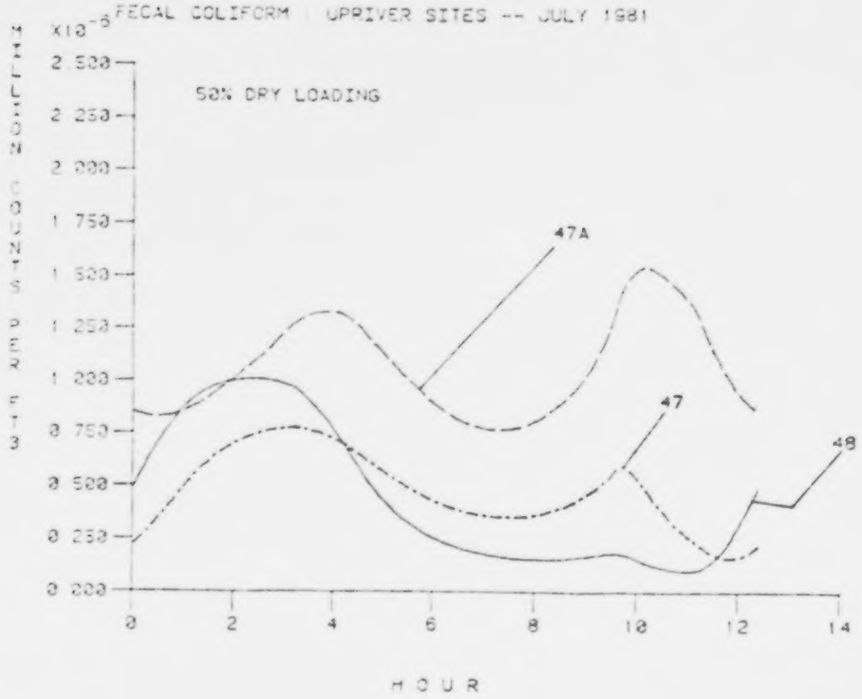


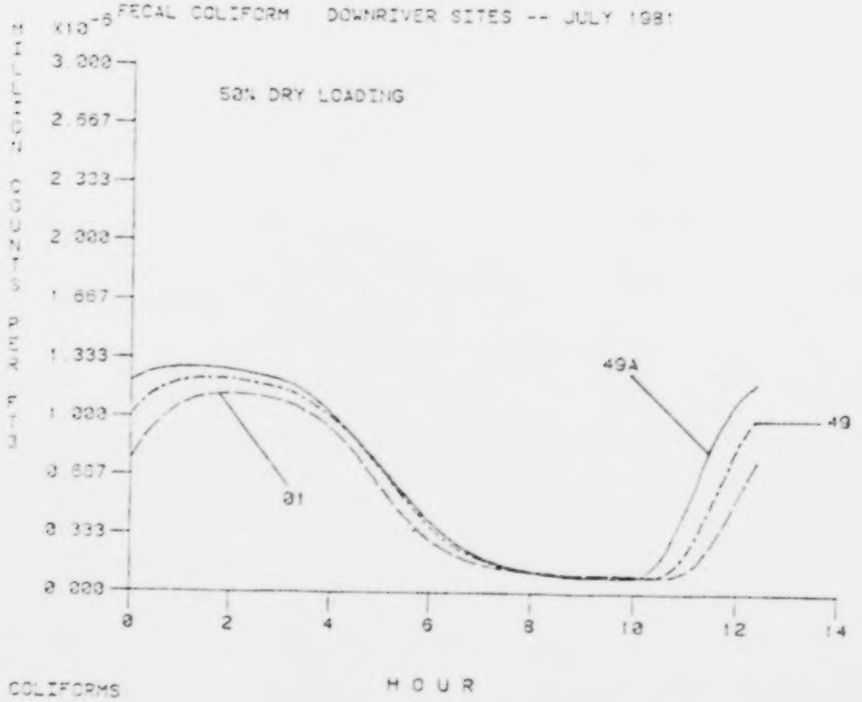
FOR FECAL COLIFORMS:

VIOLATION ABOVE

4.0E-06

FIGURE 38



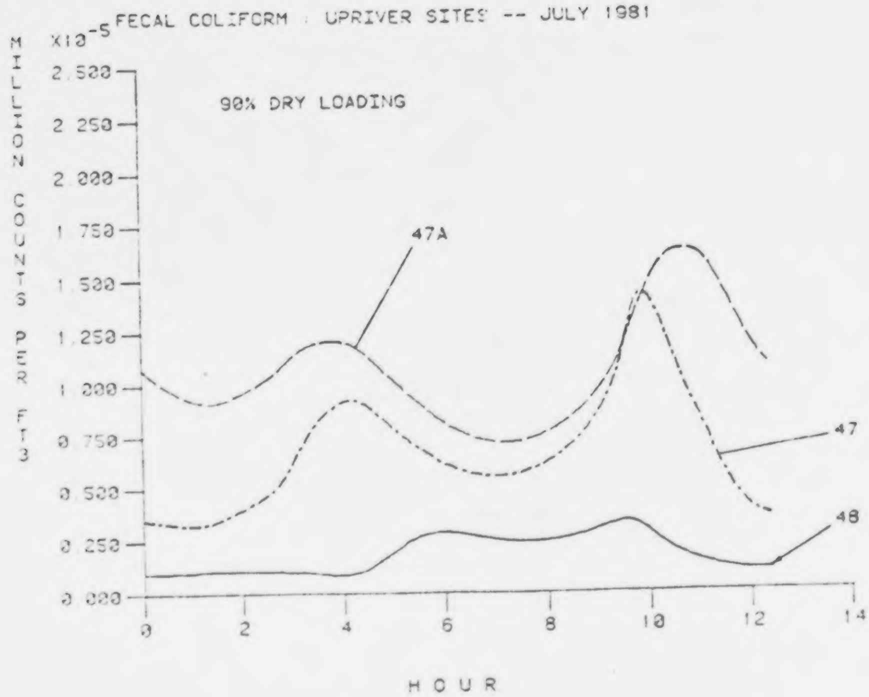


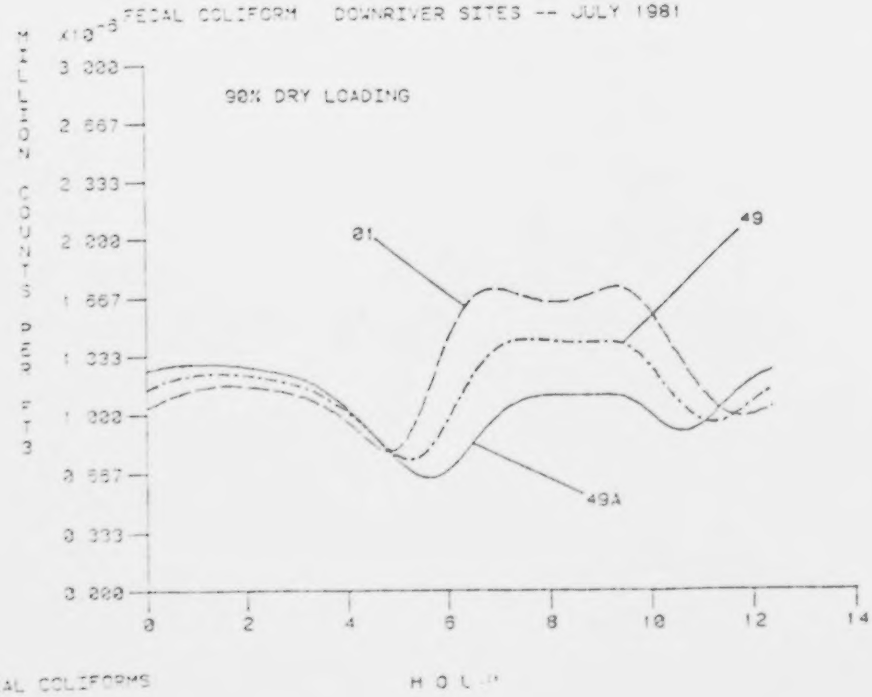
FOR FECAL COLIFORMS

VIOLATION ABOVE

4.0E-06

FIGURE 39



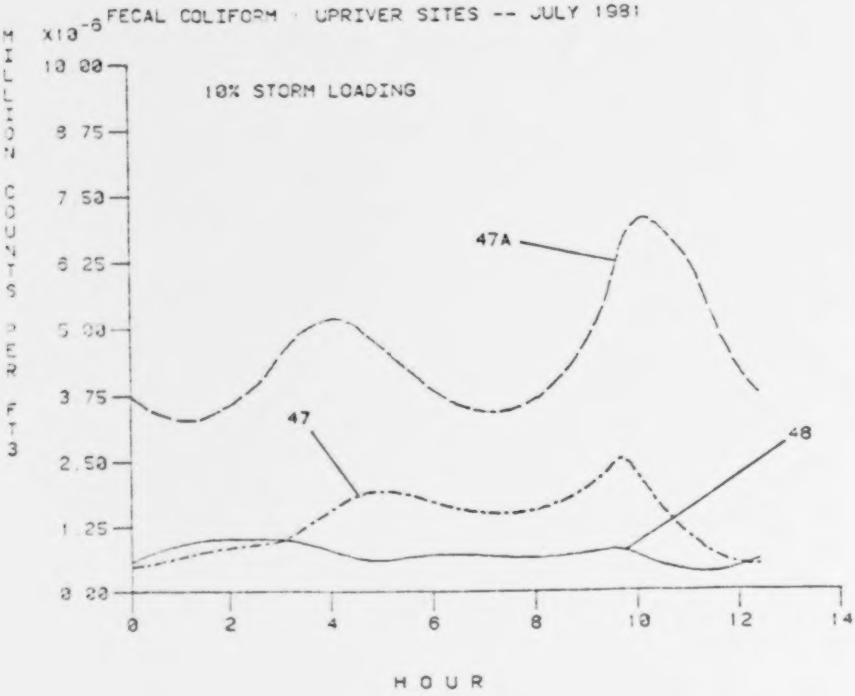


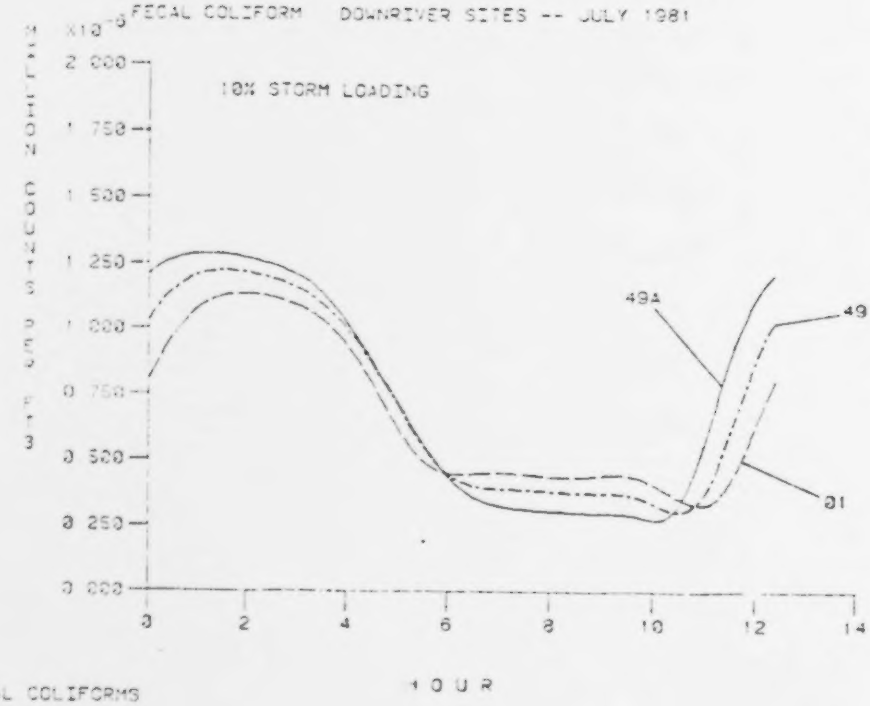
FOR FECAL COLIFORMS

VIOLATION ABOVE

4.0E-06

FIGURE 40



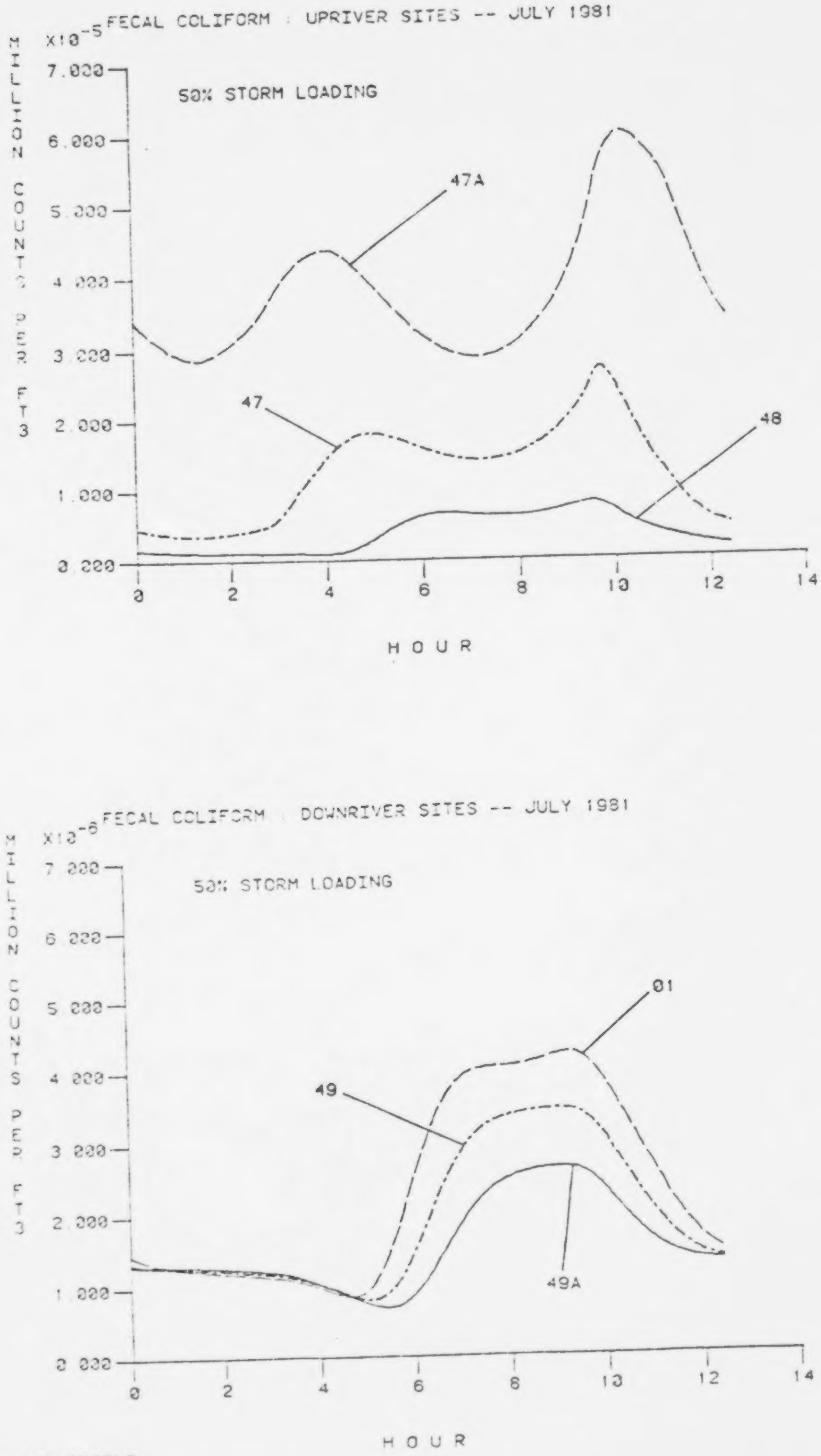


FOR FECAL COLIFORMS

VIOLATION ABOVE

4.0E-06

FIGURE 41



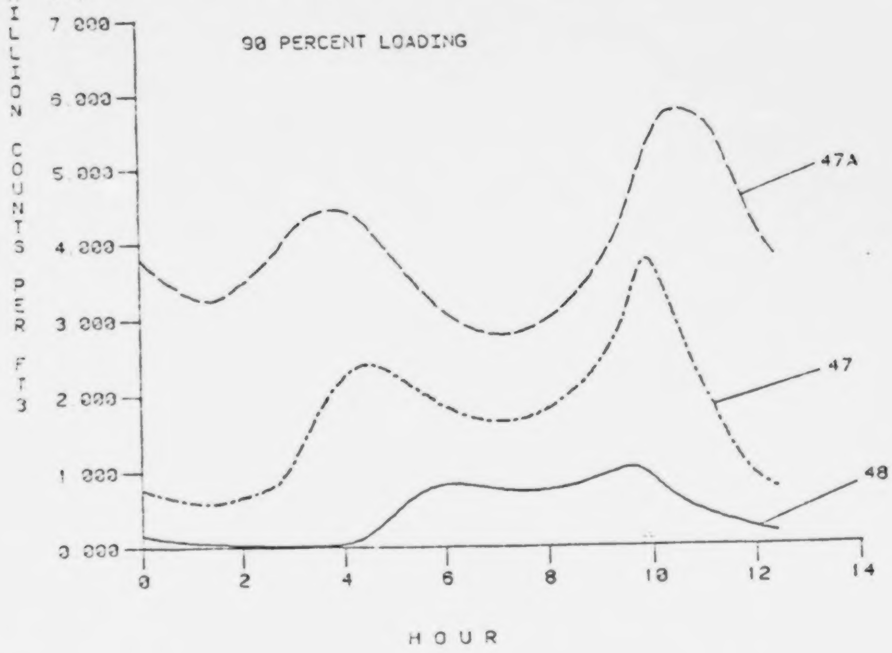
FOR FECAL COLIFORMS

VIOLATION ABOVE

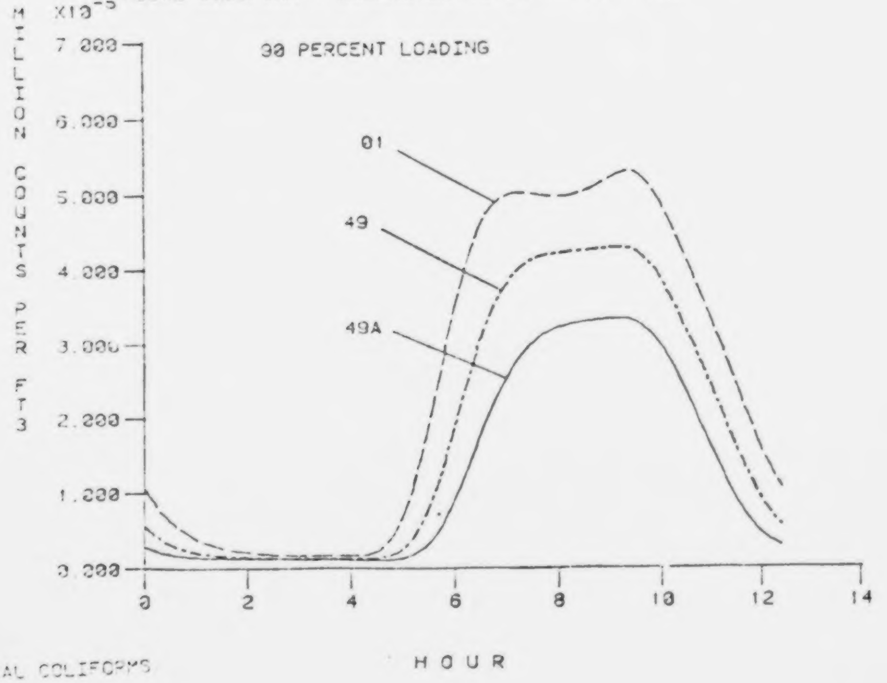
4.0E-06

FIGURE 42

FECAL COLIFORM : UPRIVER SITES -- JULY 1981



FECAL COLIFORM : DOWNRIVER SITES -- JULY 1981



FOR FECAL COLIFORMS

VIOLATION ABOVE

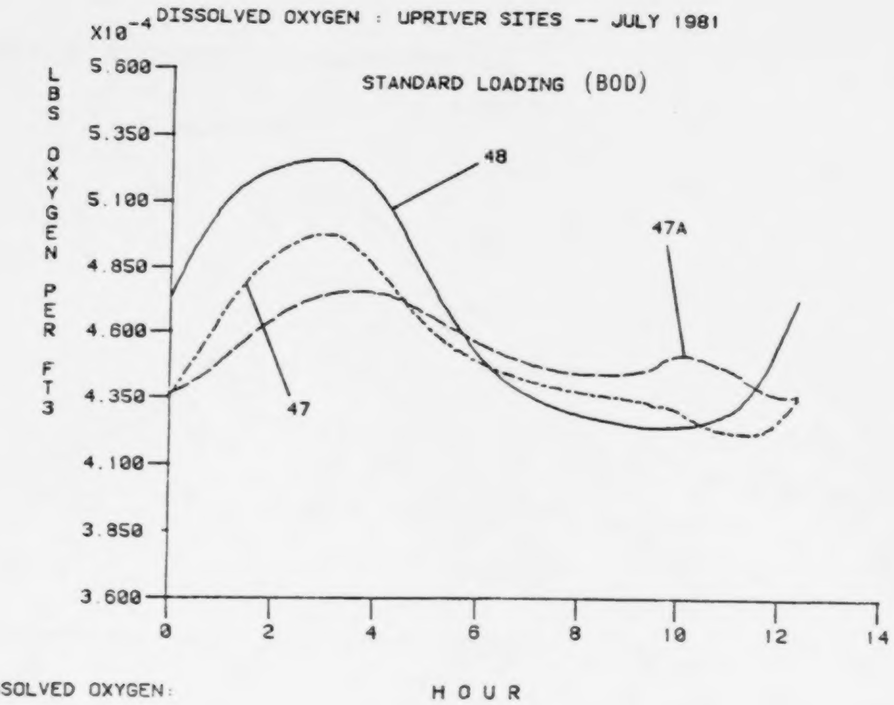
4.0E-06

but the duration of non-compliance has diminished from 7 to about 4 hours. Finally, the 10th percentile storm loading regime results in full-cycle compliance in all downriver sites, and compliance during portions of the flood tide as far upriver as section 47. Section 47A, however, still experiences violation for much of the 12.4 hours of the simulated tidal cycle.

BOD and Oxygen

As mentioned earlier, we investigated the sensitivity of our model river to BOD loading in order to determine at what exogenous input rate oxygen violations would exist (>4.1E-04 lbs/ft3). Figures 43 through 45 show the results of this analysis. Figure 43 is merely an enlargement of the first quasi-steady state tidal cycle depicted in Figure 28 for the July 1981 simulation and form a "standard" frame of reference. Note that no violations are evident according to the model output. To the "standard" upriver loading conditions represented in these graphics, we elevated the loading rates by a factor of 2 and then of 5. The effect of a 2x increase in upriver loading did little to the downriver sites as shown in Figure 44. A similar lack of system response is noted upriver and for no sampling site does oxygen fall below allowable limits. In the 5x scenario, however, we begin to see the effect of upriver loading during the ebb tide at downriver sites 49 and 01, although they still experience compliance. In contrast, the 5x loading brings about substantial changes in the upriver time-series plots (Figure 45), and station 47A failed to adhere to water quality standards for oxygen. Measurements of stormwater flow and BOD loading rates to the estuary (Phase I) suggest the 5X July "standard" loading conditions can be expected to occur in 28% of all storm runoff events. Resulting dissolved oxygen violations will likely be of short duration during ebb tides at upriver locations. Dry weather loads high enough to result in dissolved oxygen standard violations are not expected. Results for the BOD/DO analysis assume dissolved oxygen saturation (at 23°C) at the freshwater inputs and ocean boundary locations. Model predictions show no detectable impact from the Durham wastewater treatment facility discharge. Model input parameters were based upon design flows and permitted concentration discharge limits for coliform bacteria and BOD.

FIGURE 43



FOR DISSOLVED OXYGEN:

VIOLATION BELOW

4.1E-04

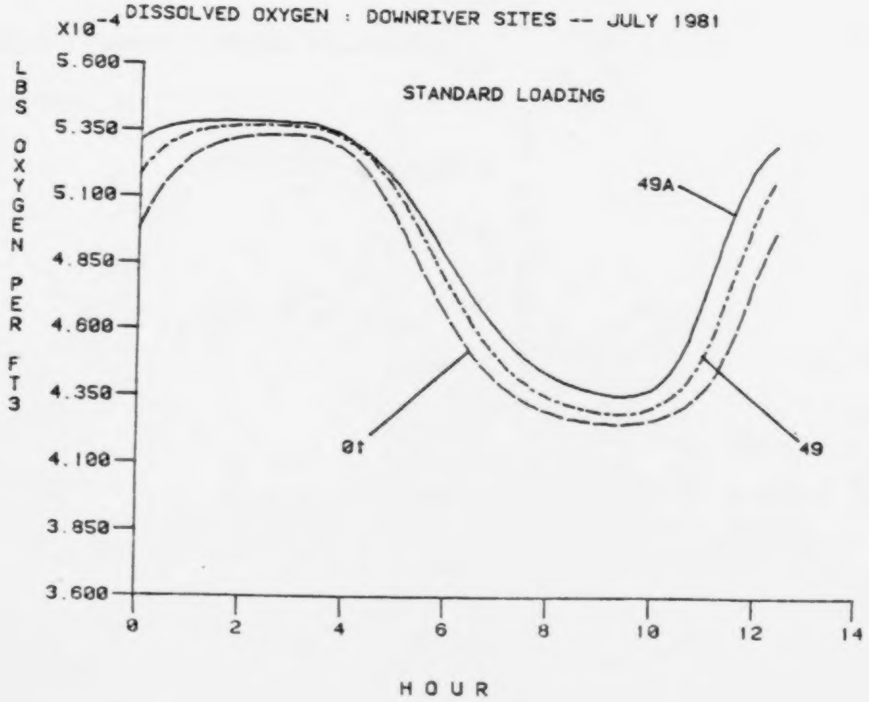
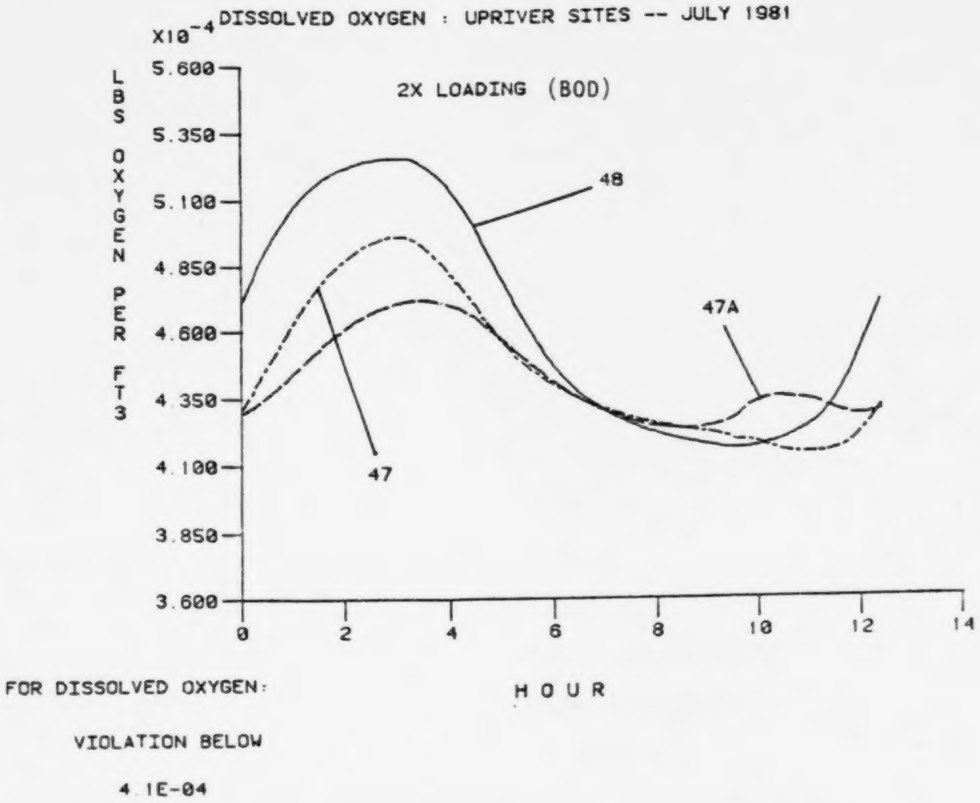


FIGURE 44


DISSOLVED OXYGEN : UPRIVER SITES -- JULY 1981
X10^{-4}
2X LOADING (BOD)
LBS OXYGEN PER FT3
5.600
5.350
5.100
4.850
4.600
4.350
4.100
3.850
3.600
0
2
4
6
8
10
12
14
HOUR
48
47A
47
FOR DISSOLVED OXYGEN:
VIOLATION BELOW
4.1E-04

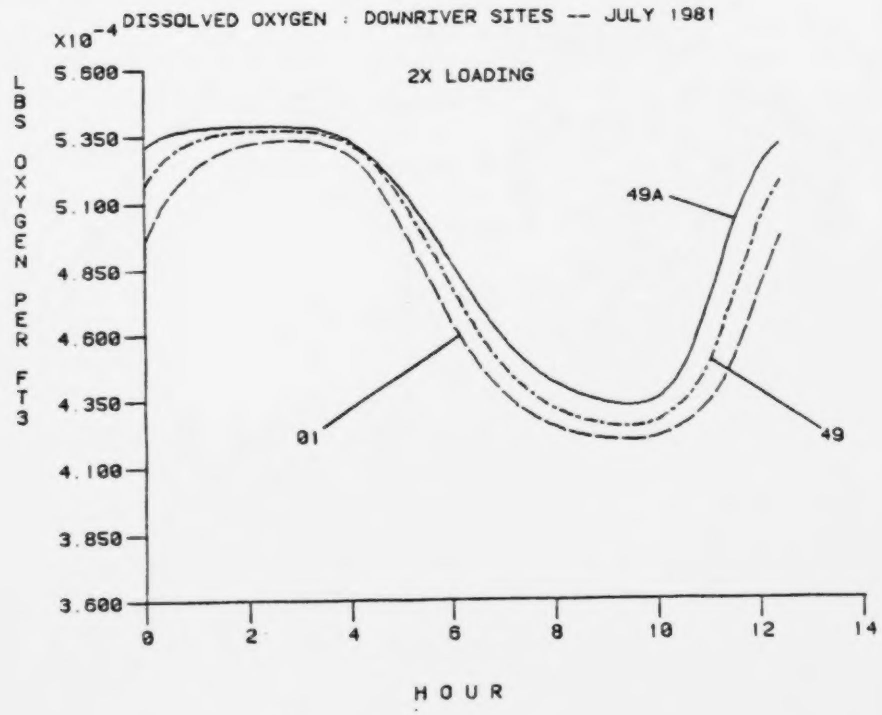
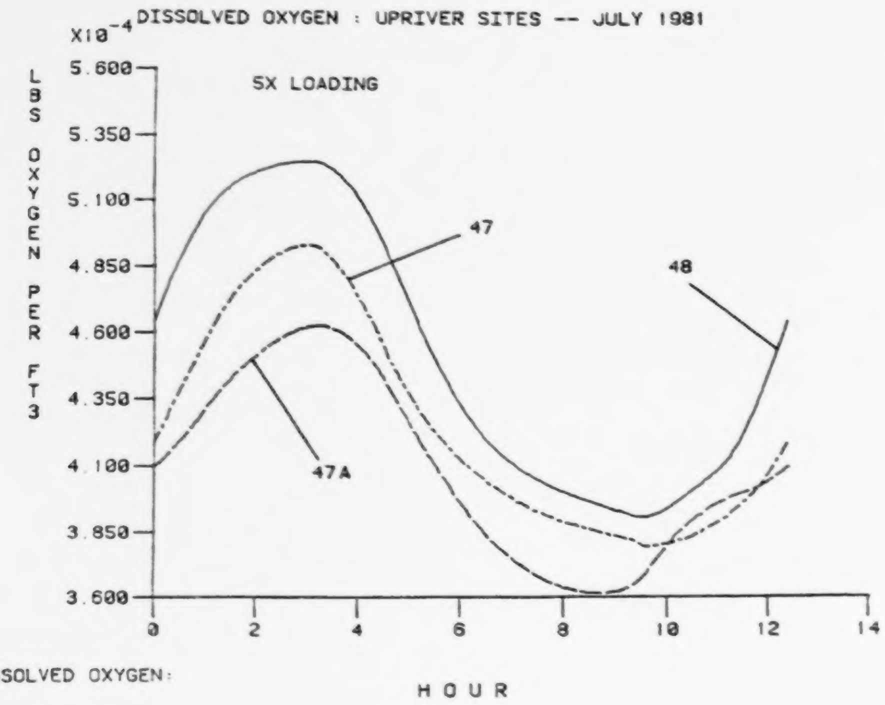

DISSOLVED OXYGEN : DOWNRIVER SITES -- JULY 1981
X10^{-4}
2X LOADING
LBS OXYGEN PER FT3
5.600
5.350
5.100
4.850
4.600
4.350
4.100
3.850
3.600
0
2
4
6
8
10
12
14
HOUR
49A
01
49

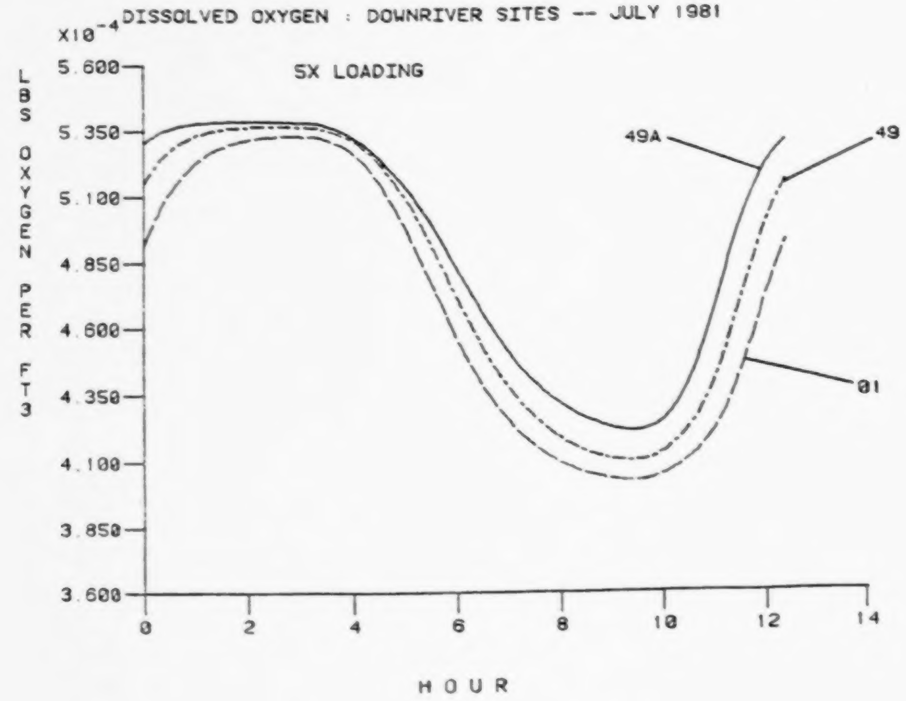
FIGURE 45



FOR DISSOLVED OXYGEN:

VIOLATION BELOW

4.1E-04



III.5 IMPACTS OF STORMWATER RUNOFF CONTROL IMPLEMENTATION ON ESTUARY WATER QUALITY

In addition to defining impacts resulting from stormwater runoff conditions, estuary modeling activities were intended to suggest improvements which could result from implementation of stormwater control devices in Durham. Since estuary water quality violations are restricted to coliform bacteria and possibly dissolved oxygen, control performance in these areas is at issue.

Coliform Bacteria

Evaluation of the three control mechanisms (river-run impoundment in Mill Pond, grassed swale treatment, and the parking lot vacuum practice), has shown that only river-run impoundment results in significant removal of coliform organisms. Nearly 60% of total coliforms and 53% of fecal coliforms were removed, presumably via natural mortality associated with time of detention in Mill Pond. Since observed estuary conditions already reflect the reduced coliform concentrations resulting from treatment in Mill Pond, large concentration increase can be expected if Mill Pond's influence were removed. Approximately 80% of coliform loads to the estuary come from the freshwater Oyster River, therefore, concentration increases up to 45% are possible.

BOD/DO

Based upon the mass loading results presented in Section I of this report (Table 37) it can be seen that runoff contributions from the impervious parking lot site account for nearly 83% of the net urban catchment BOD loads. Results of control evaluations show the vacuum cleaning practice can achieve a 58% reduction in BOD loads from the parking

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lot. Performance evaluations of the other control methods did not show significant BOD removal.

Assuming the vacuum practice can be applied to all large paved surface areas in Durham, and that BOD contributions from these areas are similar to those measured at 1-Pkg, BOD reductions approaching 50% are conceivable. If we now consider this reduced BOD input to the estuary as the "standard loading" condition used in Figure 43, then violations would not occur until load increases of 10 times are realized.

It should be noted, however, that the Town of Durham does have a street sweeping program which may already result in reduced BOD loads. Also, results of the vacuum study were based upon daily operation of the unit. Such intensive useage of a street sweeper is impractical.

III.6 SUMMARY AND CONCLUSIONS

This analysis has demonstrated that a detailed model of water quality, even when a rich database is lacking, can be successfully used in clarifying the understanding of estuarine system response to exogenous pollution loading. The model serves as a focal point for research, both answering questions and raising others. It as well alerts researchers to the existence of counterintuitive phenomena.

Early in this project, we discovered the important influence that the seaward boundary conveyed to the internal system dynamics of the estuary. We also recognized the need for detailed timeseries information about this boundary during incoming tides. It must be stressed that such detailed information is also needed about the upriver freshwater boundaries and as well a series of sites internal to the study area. In this way, an accurate quantitative picture can be secured of how the system transports and processes pollutants. Vorosmarty et al (1982) and Schmidt (1981) have already demonstrated the validity of this computer simulation in analyzing field data. Presumably, with a densely-sampled July 1981 dataset, we could have here established with certainty our quantitative estimates which, of necessity, were more cautiously offered in this document.

Nonetheless, assuming that the modeled system received accurate loading information, we have learned that:

1. Downriver boundary concentrations are quite important in determining water quality within the estuary.
2. The Pettee Brook and Oyster River above the dam convey important and distinct influences on estuarine water quality.
3. The effect of storm induced loading is propagated quickly throughout the estuary.

4. Increased loading of coliforms, even under dry conditions, can result in water quality standard violations for shellfish areas.
5. Coliform bacteria standards are violated routinely during stormwater runoff events, especially at upriver locations.
6. Under design flow and permitted BOD and coliform bacteria concentration limits, model simulations show no impact from the Durham wastewater treatment facility discharge.
7. A BOD loading of 5 times standard steady-state July inputs will result in oxygen standard violations. BOD loading rates of this magnitude can be expected in 28% of stormwater runoff events, and are not expected at all during dry weather conditions.
8. Generally, standards violations are most pronounced during ebbing tides.
9. Existing stormwater treatment provided by Mill Pond results in significant coliform bacteria reductions in the estuary.
10. Broad applications of the parking lot vacuum type of control could safeguard against potential dissolved oxygen violations in the estuary.

SECTION IV

LITERATURE CITATIONS

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Section I

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APPENDIX A

SEDIMENT OXYGEN DEMAND
OYSTER RIVER, DURHAM, NEW HAMPSHIRE
JULY 1981

PETER M. NOLAN
MICHAEL D. BILGER

OCTOBER 1981
NEW ENGLAND REGIONAL LABORATORY
U.S. ENVIRONMENTAL PROTECTION AGENCY REGION I
60 WESTVIEW STREET, LEXINGTON, MASSACHUSETTS

SEDIMENT OXYGEN DEMAND
OYSTER RIVER, DURHAM, NEW HAMPSHIRE
JULY 1981

Sediment Oxygen Demand (SOD) analysis was conducted at five locations on the fresh water portion of the Oyster River in Durham, New Hampshire during July, 1981. The study was performed at the request of the New Hampshire WS&PCC to supplement a National Urban Runoff Program project being conducted by the State on the river in the Durham area.

Methods and Materials

A modified in situ SOD test using sediment cores has been developed at the New England Regional Laboratory and used in the field to estimate benthic respiration for undisturbed sediment samples at ambient water temperature. The core sample is taken with a gravity type corer equipped with a plunger and suction flap for deep water sampling or by hand coring in shallow water.

The core tube or cylinder used measures 41 cm in height by 5.1 cm in diameter and is stopped at both ends after the sample is taken, giving an undisturbed profile of benthic material and a sample of the overlying water column. Since the core penetrates into the substrate to variable depths, depending on composition, both the sediment and water column within the core is precisely measured and the water volume then determined. Sediment surface area is always a constant for the core tube.

Dissolved oxygen is monitored simultaneously by probe (calibrated daily) for each of five replicate samples taken from each station. Self-contained stirring apparatus on each probe insures adequate flow past the sensing head and also gives total and continuous mixing within the core tube. Light and dark bottles containing overlying water from the source of the SOD sample (blanks) are run to determine if respiration or oxygen production within the water column exists so that proper compensations in SOD measurements can be made. The core tubes are placed in a shaded water bath into which water from the sample source is continuously pumped and circulated. This provides for SOD determinations at ambient temperatures under uniform conditions.

Dissolved oxygen concentrations within the core tubes are monitored for approximately three hours which normally includes a half-hour stabilization period. Given the time, change in D.O., water volume, sediment surface area, and blank corrections, sediment oxygen demand results are derived from the following equation:

$$\text{SOD gm } O_2/m^2/\text{day} = \frac{\left[(O_i - O_f) - (B_i - B_f)\right] \; V}{SA \qquad (t)}$$

O_i = DO initial mg/l

O_f = DO final mg/l

B_i = Blank DO initial mg/l

B_f = Blank DO final mg/l

V = Volume confined water (m^3)

SA = Sediment area (m^2)

t = time/days

In the final determination of benthic respiration, a rate is obtained by plotting time vs. oxygen depletion. That portion of each rate, where oxygen consumption versus time is constant, is used in calculation of the rate. Appropriate corrections are made for any respiration or production encountered in the water blanks.

Results

The sediment composition at stations ORNH01, 02 and 04 were similar (fine organic mud) and ORNH03 and 05 had similar substrates composed of organic mud mixed with decaying vegetation, leaves and algae. The station locations are shown in figure 1. The sediment oxygen demand data for each of five replicate analysis for the stations sampled, together with a statistical evaluation including the mean, standard error, and upper and lower 95% confidence limits are listed in Tables 1, 2, 3, 4, and 5.

In general, the range of SOD rates measured for the Oyster River fall within values which can be considered moderate to high. The highest mean rates were recorded at stations ORNH03 and ORNH05. Both of these stations are located at the head of impounded areas created by dams, where, as indicated by the nature of the substrate, it appears that leaves, dead vegetation, and algae accumulate on the bottom, decompose, and exert the observed higher rates of respiration.

TABLE 1
Sediment Oxygen Demand (SOD)
Oyster River, Durham, New Hampshire
July 1981

tation	Lab No.	Date of Test	Type of Test	Temp °C	SOD Rate gm O_2/m^2/day	Mean Rate ± Standard Error	95% Confidence Limits Upper	95% Confidence Limits Lower	Sediment Description	Comment
ORNHO1 R_1	43347	7/13/81	In situ core	22-24	4.45	3.82 ± 0.27	4.58	3.07	Fine Organic Mud	
ORNHO1 R_2	43347	7/13/81	In situ core	22-24	2.98					
ORNHO1 R_3	43347	7/13/81	In situ core	22-24	3.90					
ORNHO1 R_4	43347	7/13/81	In situ core	22-24	4.31					
ORNHO1 R_5	43347	7/13/81	In situ core	22-24	3.47					

TABLE 2
Sediment Oxygen Demand (SOD)

tation	Lab No.	Date of Test	Type of Test	Temp °C	SOD Rate gm O_2/m^2/day	Mean Rate ± Standard Error	95% Confidence Limits		Sediment Description	Comments
							Upper	Lower		
ORNHO2 R_1	43348	7/14/81	In situ core	23	3.10	2.94 ± 0.38	4.01	1.88	Organic Mud	
ORNHO2 R_2	43348	7/14/81	In situ core	23	4.31					
ORNHO2 R_3	43348	7/14/81	In situ core	23	2.64					
ORNHO2 R_4	43348	7/14/81	In situ core	23	2.01					
ORNHO2 R_5	43348	7/14/81	In situ core	23	2.67					

TABLE 3
Sediment Oxygen Demand (SOD)
Oyster River, Durham, New Hampshire
July 1981

Station	Lab No.	Date of Test	Type of Test	Temp °C	SOD Rate gm O_2/m^2/day	Mean Rate ± Standard Error	95% Confidence Limits		Sediment Description	Comment
							Upper	Lower		
ORNHO3 R_1	43349	7/15/81	In situ core	25	4.86	4.52 ±0.43	3.34	5.71	Organic mud Decomposing leaves and vegetation	
ORNHO3 R_2	43349	7/15/81	In situ core	25	3.47					
ORNHO3 R_3	43349	7/15/81	In situ core	25	3.59					
ORNHO3 R_4	43349	7/15/81	In situ core	25	5.63					
ORNHO3 R_5	43349	7/15/81	In situ core	25	5.08					

TABLE 4

Sediment Oxygen Demand (SOD)

Oyster River, Durham, New Hampshire
July 1981

tation	Lab No.	Date of Test	Type of Test	Temp °C	SOD Rate gm O_2/m^2/day	Mean Rate ± Standard Error	95% Confidence Limits		Sediment Description	Comments
							Upper	Lower		
RNHO4 R_1	43300	7/16/81	In situ core	22-26	2.03	2.73 ±0.22	3.36	2.11	Fine Organic Mud	
RNHO4 R_2	43300	7/16/81	In situ core	22-26	3.08					
RNHO4 R_3	43300	7/16/81	In situ core	22-26	3.01					
RNHO4 R_4	43300	7/16/81	In situ core	22-26	3.18					
RNHO4 R_5	43300	7/16/81	In situ core	22-26	2.39					

TABLE 5
Sediment Oxygen Demand (SOD)
Oyster River, Durham, New Hampshire
July 1981

tation	Lab No.	Date of Test	Type of Test	Temp °C	SOD Rate gm O_2/m^2/day	Mean Rate ± Standard Error	95% Confidence Limits		Sediment Description	Comments
							Upper	Lower		
ORNHO5 R_1	44153	7/17/81	In situ core	21	7.70	5.91 ±0.57	7.48	4.33	Fine mud Decaying vegetation Algae	
ORNHO5 R_2	44153	7/17/81	In situ core	21	6.07					
ORNHO5 R_3	44153	7/17/81	In situ core	21	5.57					
ORNHO5 R_4	44153	7/17/81	In situ core	21	4.16					
ORNHO5 R_5	44153	7/17/81	In situ core	21	6.05					

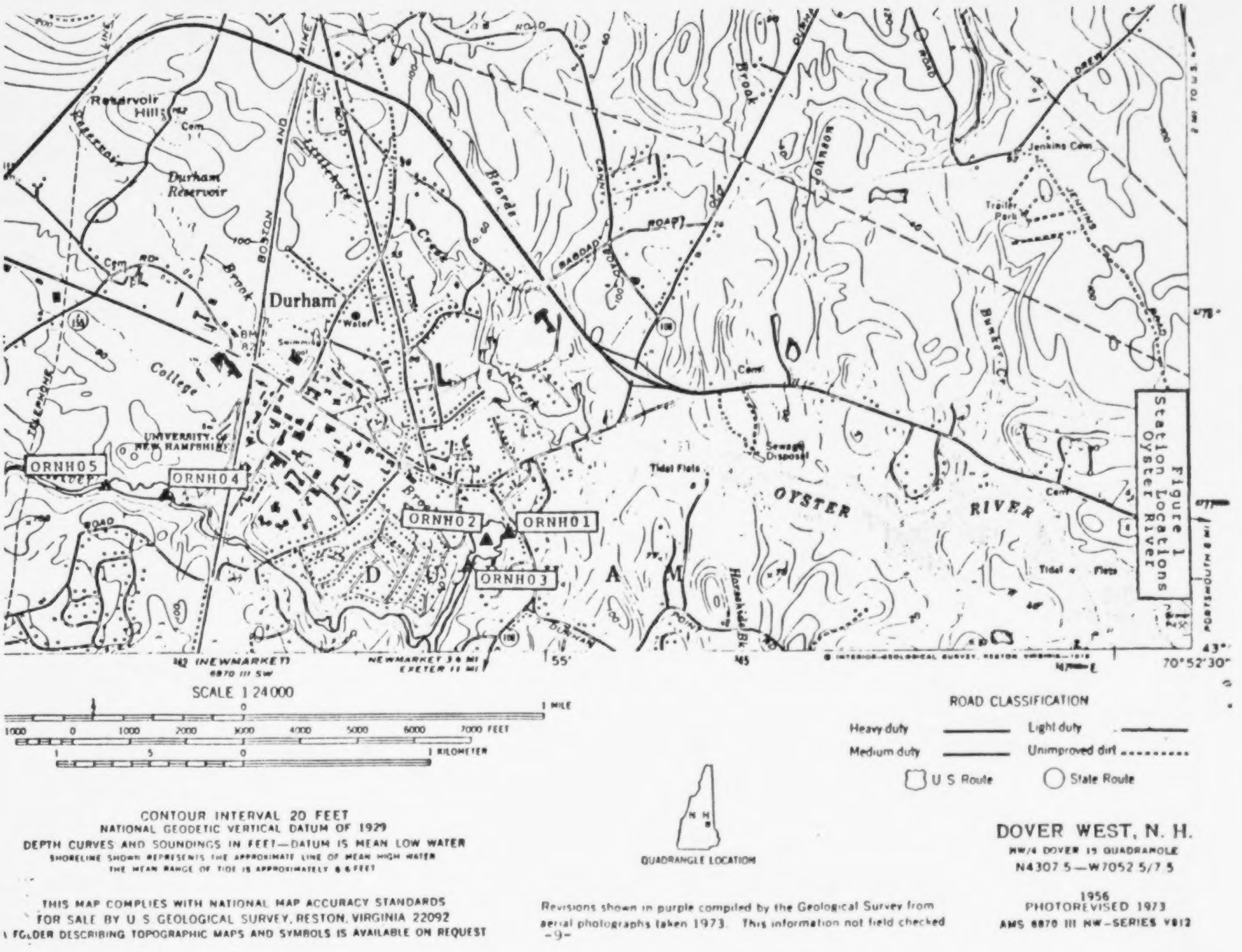


Figure 1 Station Locations Oyster River

ORNH05
ORNH04
ORNH02
ORNH01
ORNH03
Reservoir Hill
Durham Reservoir
Durham
College
UNIVERSITY OF NEW HAMPSHIRE
OYSTER RIVER
Tidal Flats
Sewage Disposal
Jenkins Cem
Trailer Park
(NEWMARKET)
NEWMARKET 3.6 MI
EXETER 11 MI
55'
70°52'30"
43°
SCALE 1:24000
1 MILE
1000 0 1000 2000 3000 4000 5000 6000 7000 FEET
1 .5 0 1 KILOMETER
ROAD CLASSIFICATION
Heavy duty
Light duty
Medium duty
Unimproved dirt
U S Route
State Route
CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929
DEPTH CURVES AND SOUNDINGS IN FEET—DATUM IS MEAN LOW WATER
SHORELINE SHOWN REPRESENTS THE APPROXIMATE LINE OF MEAN HIGH WATER
THE MEAN RANGE OF TIDE IS APPROXIMATELY 6.6 FEET
N H
QUADRANGLE LOCATION
DOVER WEST, N. H.
NW/4 DOVER 15' QUADRANGLE
N4307.5—W7052.5/7.5
1956
PHOTOREVISED 1973
AMS 6870 III NW—SERIES V812
THIS MAP COMPLIES WITH NATIONAL MAP ACCURACY STANDARDS
FOR SALE BY U S GEOLOGICAL SURVEY, RESTON, VIRGINIA 22092
A FOLDER DESCRIBING TOPOGRAPHIC MAPS AND SYMBOLS IS AVAILABLE ON REQUEST
Revisions shown in purple compiled by the Geological Survey from aerial photographs taken 1973. This information not field checked

APPENDIX B

Urban Stormwater Runoff
Mass Loading Data

1980-81 MASS LOADING SUMMARY FOR STATION: ENTIRE OYS (5-OYS)

SUBSTANCE	MEAN LOAD	LBS/IN.PRECIP	LBS/YEAR	LBS/DAY	LBS/ACRE/IN.PRECIP	LBS/ACRE/YEAR
BOD	4019.812988	5021.282227	210341.500000	576.278076	0.394104	16.509026
COD	23426.207031	27705.121094	1160567.500000	3179.636719	2.174485	91.089188
TKN	441.563721	580.580811	24320.527344	66.631577	0.045568	1.908840
NH3	71.251907	90.192337	3778.156738	10.351114	0.007079	0.296535
NO2+NO3	184.589813	218.306061	9144.839844	25.054356	0.017134	0.717749
DIS PHOS	10.020798	11.851149	496.444580	1.360122	0.000930	0.038964
TOTAL PHOS	44.558258	52.697052	2207.479004	6.047889	0.004136	0.173258
CADMIUM	3.831195	4.530982	189.802826	0.520008	0.000356	0.014897
CHROMIUM	13.338444	15.774778	660.805420	1.810426	0.001238	0.051864
COPPER	58.274925	68.919128	2887.021973	7.909650	0.005409	0.226593
IRON	625.851074	782.857788	32793.906250	89.846329	0.061444	2.573888
LEAD	8.255224	9.763083	408.975464	1.120481	0.000766	0.032099
MAGNESIUM	1656.804443	1959.427979	82080.421875	224.877899	0.153789	6.442227
MANGANESE	49.265625	61.624855	2581.464844	7.072507	0.004837	0.202611
POTASSIUM	1398.646484	1877.378906	78643.390625	215.461365	0.147349	6.172465
SODIUM	8503.525391	10398.337891	435586.312500	1193.387207	0.816132	34.187759
ZINC	41.756180	49.383156	2068.660156	5.667562	0.003876	0.162362
TOT SOLIDS	74013.015625	87531.875000	3666710.000000	10045.781250	6.870093	287.788208
SUSP SOLID	4069.727051	5499.633789	230379.625000	631.177124	0.431648	18.081753
TOT VOLAT	25918.878906	37868.507813	1586311.750000	4346.059570	2.972177	124.504486
SUSP VOLAT	962.496460	1406.245605	58907.625000	161.390747	0.110372	4.623469
DIS CD	1.064761	3.465769	145.181061	0.397756	0.000272	0.011395
DIS CR	2.129522	6.931539	290.362122	0.795513	0.000544	0.022790
DIS CU	21.295223	69.315399	2903.621582	7.955129	0.005440	0.227896
DIS FE	132.284607	430.582947	18037.117188	49.416763	0.033795	1.415675
DIS PB	2.197427	7.152570	299.621094	0.820880	0.000561	0.023516
DIS MG	577.105103	1878.462119	78688.765625	215.585693	0.147434	6.176027
DIS MN	5.548433	21.249325	890.134155	2.438724	0.001668	0.069864
DIS K	461.898865	1652.918945	69240.765625	189.700745	0.129732	5.434484
DIS NA	3335.560059	11936.402344	500015.875000	1369.906494	0.936850	39.244629
DIS ZN	9.975965	32.471504	1360.231201	3.726661	0.002549	0.106760

** ALL MASS IS IN POUNDS **

1980-81 MASS LOADING SUMMARY FOR STATION: UPPER OYS (7-OYS)

10 X

SUBSTANCE	MEAN LOAD	LBS/IN.PRECIP	LBS/YEAR	LBS/DAY	LBS/ACRE/IN.PRECIP	LBS/ACRE/YEAR
BOD	1253.214600	1578.356689	66117.359375	181.143433	1.494656	62.611130
COD	6250.973633	7722.022461	323475.500000	886.234253	7.312520	306.321472
TKN	126.038132	171.948425	7202.918945	19.734024	0.162830	6.820946
NH3	33.409828	43.989265	1842.710205	5.048521	0.041657	1.744991
NO2+NO3	77.306870	98.542908	4127.961914	11.309484	0.093317	3.909055
DIS PHOS	2.295195	3.044026	127.514252	0.349354	0.002883	0.120752
TOTAL PHOS	13.958946	17.243919	722.347656	1.979035	0.016329	0.684041
CADMIUM	1.093977	1.351424	56.611153	0.155099	0.001280	0.053609
CHROMIUM	4.938505	6.100689	255.557831	0.700158	0.005777	0.242005
COPPER	18.714645	23.118782	968.445679	2.653276	0.021893	0.917089
IRON	167.071198	217.540771	9112.781250	24.966526	0.206005	8.629526
LEAD	1.936548	2.392279	100.212540	0.274555	0.002265	0.094898
MAGNESIUM	456.198975	563.556763	23607.390625	64.677780	0.533671	22.355480
MANGANESE	14.485537	17.894432	749.597656	2.053692	0.016945	0.709846
POTASSIUM	692.510132	930.793701	38990.945313	106.824509	0.881433	36.923241
SODIUM	2211.495605	2731.929199	114440.500000	313.535645	2.587054	108.371674
ZINC	19.235958	23.762775	995.422607	2.727185	0.022503	0.942635
TOT SOLIDS	19834.367188	24502.011719	1026389.250000	2812.024902	23.202660	971.959473
SUSP SOLID	752.688721	929.819824	38950.148438	106.712738	0.880511	36.884605
TOT VOLAT	7081.140625	9323.427734	390558.375000	1070.022949	8.829002	369.846924
SUSP VOLAT	270.512085	375.450684	15727.628906	43.089394	0.355540	14.893587
DIS CD	0.264985	0.958355	40.145470	0.109988	0.000908	0.038017
DIS CR	0.529970	1.916709	80.290939	0.219975	0.001815	0.07603
DIS CU	5.299698	19.167088	802.909180	2.199751	0.018151	0.760331
DIS FE	30.070652	127.960251	5360.253906	14.685629	0.121174	5.075997
DIS PB	0.529970	1.916709	80.290939	0.219975	0.001815	0.07603
DIS MG	140.302734	507.424255	21256.000000	58.235619	0.480515	20.128784
DIS MN	1.647475	5.958321	249.594025	0.683819	0.005642	0.236358
DIS K	95.306335	344.688538	14439.001953	39.558907	0.326410	13.673298
DIS NA	724.586182	2620.565918	109775.500000	300.754761	2.481596	103.954071
DIS ZN	4.609208	16.669838	698.299438	1.913149	0.015786	0.661268

** ALL MASS IS IN POUNDS **

1980-81 MASS LOADING SUMMARY FOR STATION: ENTIRE PTE (2-PTE)

SUBSTANCE	MEAN LOAD	LBS/IN.PRECIP	LBS/YEAR	LBS/DAY	LBS/ACRE/IN.PRECIP	LBS/ACRE/YEAR
BOD	193.244141	336.727600	14105.517578	38.645256	0.467029	19.563824
COD	778.843750	1252.832520	52481.148438	143.783966	1.737632	72.789383
TKN	14.887970	32.326126	1354.141357	3.709976	0.044835	1.878143
NH3	1.027746	2.019589	84.600586	0.231782	0.002801	0.117338
NO2+NO3	4.796357	8.497488	355.959717	0.975232	0.011786	0.493703
DIS PHOS	0.209399	0.336834	14.109991	0.038658	0.000467	0.019570
TOTAL PHOS	1.189179	2.642622	110.699402	0.303286	0.003665	0.153536
CADMIUM	0.077481	0.143190	5.998210	0.016433	0.000199	0.008319
CHROMIUM	0.286868	0.461451	19.330166	0.052959	0.000640	0.026810
COPPER	1.102781	1.843089	77.207001	0.211526	0.002556	0.107083
IRON	95.199997	153.136810	6414.900391	17.575069	0.212395	8.897226
LEAD	1.282372	2.062799	86.410614	0.236741	0.002861	0.119848
MAGNESIUM	42.171921	67.836914	2841.687988	7.785447	0.094087	3.941315
MANGANESE	6.456477	10.385761	435.059509	1.191944	0.014405	0.603411
POTASSIUM	16.605709	61.756805	2586.992188	7.087650	0.085654	3.588061
SODIUM	290.349731	626.654541	26250.554688	71.919327	0.869146	36.408531
ZINC	1.487820	2.393277	100.254349	0.274669	0.003319	0.139049
TOT SOLIDS	3344.130859	5379.301758	225338.937500	617.366943	7.460891	312.536621
SUSP SOLID	1842.185303	3891.942871	163033.468750	446.667053	5.397979	226.121307
TOT VOLAT	439.314819	1432.549072	60009.476563	164.409515	1.986892	83.230896
SUSP VOLAT	269.347473	878.307495	36792.296875	100.800812	1.218179	51.029533
DIS CD	0.005619	0.112379	4.707567	0.012897	0.000156	0.006529
DIS CR	0.028336	0.283359	11.869909	0.032520	0.000393	0.016463
DIS CU	0.283359	2.833590	118.699081	0.325203	0.003930	0.164631
DIS FE	0.597919	5.979191	250.468292	0.686214	0.008293	0.347390
DIS PB	0.028336	0.283359	11.869909	0.032520	0.000393	0.016463
DIS MG	7.025373	70.253738	2942.928711	8.062819	0.097439	4.081732
DIS MN	0.165880	1.658800	69.487122	0.190376	0.002301	0.096376
DIS K	1.216840	54.757782	2293.803223	6.284392	0.075947	3.181419
DIS NA	5.616183	252.728271	10586.787109	29.004894	0.350525	14.683475
DIS ZN	0.102106	1.021057	42.772057	0.117184	0.001416	0.059323

** ALL MASS IS IN POUNDS **

1980-81 MASS LOADING SUMMARY FOR STATION: UPPER PTE (3-PTE)

SUBSTANCE	MEAN LOAD	LBS/IN.PRECIP	LBS/YEAR	LBS/DAY	LBS/ACRE/IN.PRECIP	LBS/ACRE/YEAR
BOD	55.441742	93.092514	3899.645020	10.683958	0.151370	6.340886
COD	278.500183	452.437378	18952.597656	51.924934	0.735670	30.817230
TKN	20.421795	44.341682	1857.472900	5.088966	0.072100	3.020281
NH3	0.578911	1.141336	47.810547	0.130988	0.001856	0.077741
NO2+NO3	3.134333	5.347680	224.014313	0.613738	0.008695	0.364251
DIS PHOS	0.145936	0.234959	9.842445	0.026966	0.000382	0.016004
TOTAL PHOS	1.147578	2.433029	101.919586	0.279232	0.003956	0.165723
CADMIUM	0.163681	0.290844	12.183462	0.033379	0.000473	0.019811
CHROMIUM	0.190437	0.296017	12.400143	0.033973	0.000481	0.020163
COPPER	0.620594	0.964654	40.409363	0.110711	0.001569	0.065706
IRON	53.697578	83.467789	3496.465332	9.579357	0.135720	5.685309
LEAD	0.367245	0.570847	23.912773	0.065514	0.000928	0.038883
MAGNESIUM	25.596531	39.787376	1666.693115	4.566282	0.064695	2.710070
MANGANESE	2.040077	3.171106	132.837616	0.363939	0.005156	0.215996
POTASSIUM	6.846929	30.734356	1287.461914	3.527293	0.049975	2.093434
SODIUM	93.291443	151.556580	6348.704102	17.393711	0.246433	10.323095
ZINC	0.678040	1.053948	44.149895	0.120959	0.001714	0.071788
TOT SOLIDS	1854.374512	2933.106934	122867.843750	336.624207	4.769279	199.785095
SUSP SOLID	916.184448	1602.655762	67135.234375	183.932159	2.605944	109.162979
TOT VOLAT	132.529114	579.010986	24254.769531	66.451416	0.941481	39.438644
SUSP VOLAT	28.905197	112.617722	4717.555664	12.924810	0.183118	7.670822
DIS CD	0.002480	0.049606	2.078011	0.005693	0.000081	0.003379
DIS CR	0.004961	0.099213	4.156021	0.011386	0.000161	0.006758
DIS CU	0.049606	0.992128	41.560219	0.113864	0.001613	0.067578
DIS FE	0.148819	2.976381	124.680603	0.341591	0.004840	0.202733
DIS PB	0.004961	0.099213	4.156021	0.011386	0.000161	0.006758
DIS MG	1.236357	24.727146	1035.820068	2.837863	0.040207	1.684260
DIS MN	0.063348	1.266956	53.072784	0.145405	0.002060	0.086297
DIS K	0.469499	21.127441	885.028442	2.424736	0.034354	1.439070
DIS NA	1.946702	87.601608	3669.630859	10.053783	0.142442	5.966879
DIS ZN	0.014882	0.297638	12.468061	0.034159	0.000484	0.020273

** ALL MASS IS IN POUNDS **

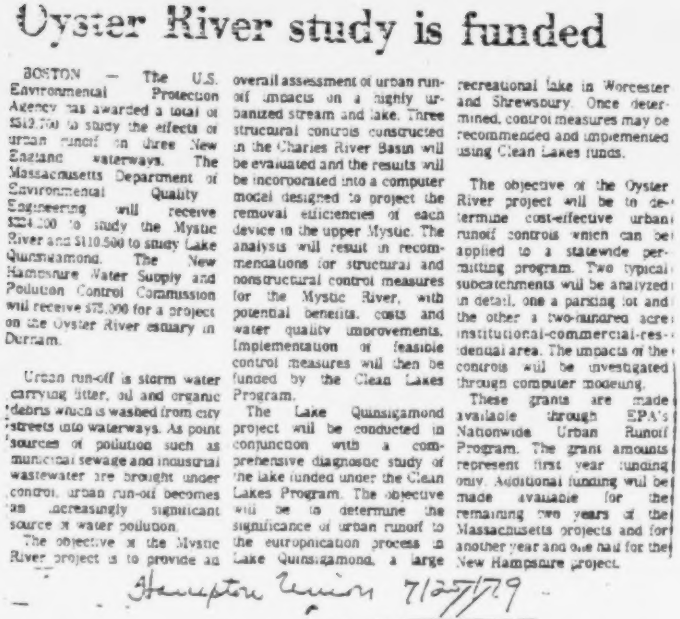
```
 1980-81 MASS LOADING SUMMARY FOR STATION: ENTIRE PKG  (1-PKG)

SUBSTANCE              MEAN LOAD    LBS/IN.PRECIP         LBS/YEAR          LBS/DAY  LBS/ACRE/IN.PRECIP     LBS/ACRE/YEAR

   BOD                  0.804368         1.837940        76.991302         0.210935            2.386935         99.988693
   COD                  3.667388         8.756416       366.806213         1.004949           11.371969        476.371704
   TKN                  0.062533         0.205622         8.613495         0.023599            0.267041         11.186356
   NH3                  0.027608         0.066058         2.767181         0.007581            0.085790          3.593741
   NO2+NO3              0.032564         0.081590         3.417801         0.009364            0.105961          4.438703
   DIS PHOS             0.001887         0.005216         0.218500         0.000599            0.006774          0.283766
   TOTAL PHOS           0.009987         0.026800         1.122655         0.003076            0.034805          1.457993
   CADMIUM              0.000252         0.000660         0.027641         0.000076            0.000857          0.035897
   CHROMIUM             0.000968         0.002430         0.101785         0.000279            0.003156          0.132188
   COPPER               0.004653         0.011685         0.489479         0.001341            0.015175          0.635687
   IRON                 0.078682         0.181123         7.587233         0.020787            0.235224          9.853548
   LEAD                 0.008757         0.020157         0.844390         0.002313            0.026178          1.096610
   MAGNESIUM            0.047987         0.110465         4.627396         0.012678            0.143462          6.009604
   MANGANESE            0.004287         0.009869         0.413428         0.001133            0.012817          0.536920
   POTASSIUM            0.061743         0.193303         8.097448         0.022185            0.251042         10.516167
   SODIUM               0.130449         0.326844        13.691500         0.037511            0.424473         17.781166
   ZINC                 0.022292         0.051316         2.149610         0.005889            0.066644          2.791700
   TOT SOLIDS           4.695051        10.606775       444.317810         1.217309           13.775032        577.036011
   SUSP SOLID           2.621656         6.126216       256.627136         0.703088            7.956125        333.281982
   TOT VOLAT            1.898309         5.460452       228.738312         0.626680            7.091496        297.062744
   SUSP VOLAT           1.063853         3.267484       136.874878         0.375000            4.243484        177.759583
   DIS CD               0.000152         0.000659         0.027608         0.000076            0.000856          0.035855
   DIS CR               0.000295         0.001281         0.053670         0.000147            0.001664          0.069701
   DIS CU               0.002888         0.012556         0.525967         0.001441            0.016306          0.683074
   DIS FE               0.008394         0.036496         1.528818         0.004189            0.047397          1.985478
   DIS PB               0.001662         0.007228         0.302791         0.000830            0.009387          0.393235
   DIS MG               0.007479         0.032301         1.353075         0.003707            0.041949          1.757241
   DIS MN               0.001249         0.005429         0.227400         0.000623            0.007050          0.295325
   DIS K                0.016781         0.084152         3.525107         0.009658            0.109288          4.578060
   DIS NA               0.050757         0.254535        10.662458         0.029212            0.330565         13.847347
   DIS ZN               0.009303         0.040446         1.694296         0.004642            0.052528          2.200385
    ** ALL MASS IS IN POUNDS **
```

APPENDIX C

PUBLIC PARTICIPATION



Oyster River study is funded

BOSTON — The U.S. Environmental Protection Agency has awarded a total of $319,700 to study the effects of urban runoff on three New England waterways. The Massachusetts Department of Environmental Quality Engineering will receive $224,200 to study the Mystic River and $110,500 to study Lake Quinsigamond. The New Hampshire Water Supply and Pollution Control Commission will receive $75,000 for a project on the Oyster River estuary in Durham.

Urban run-off is storm water carrying litter, oil and organic debris which is washed from city streets into waterways. As point sources of pollution such as municipal sewage and industrial wastewater are brought under control, urban run-off becomes an increasingly significant source of water pollution.

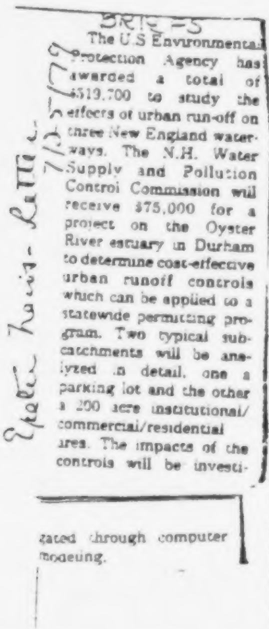
The objective of the Mystic River project is to provide an overall assessment of urban run-off impacts on a highly urbanized stream and lake. Three structural controls constructed in the Charles River Basin will be evaluated and the results will be incorporated into a computer model designed to project the removal efficiencies of each device in the upper Mystic. The analysis will result in recommendations for structural and nonstructural control measures for the Mystic River, with potential benefits, costs and water quality improvements. Implementation of feasible control measures will then be funded by the Clean Lakes Program.

The Lake Quinsigamond project will be conducted in conjunction with a comprehensive diagnostic study of the lake funded under the Clean Lakes Program. The objective will be to determine the significance of urban runoff to the eutrophication process in Lake Quinsigamond, a large recreational lake in Worcester and Shrewsbury. Once determined, control measures may be recommended and implemented using Clean Lakes funds.

The objective of the Oyster River project will be to determine cost-effective urban runoff controls which can be applied to a statewide permitting program. Two typical subcatchments will be analyzed in detail, one a parking lot and the other a two-hundred acre institutional-commercial-residential area. The impacts of the controls will be investigated through computer modeling.

These grants are made available through EPA's Nationwide Urban Runoff Program. The grant amounts represent first year funding only. Additional funding will be made available for the remaining two years of the Massachusetts projects and for another year and one half for the New Hampshire project.

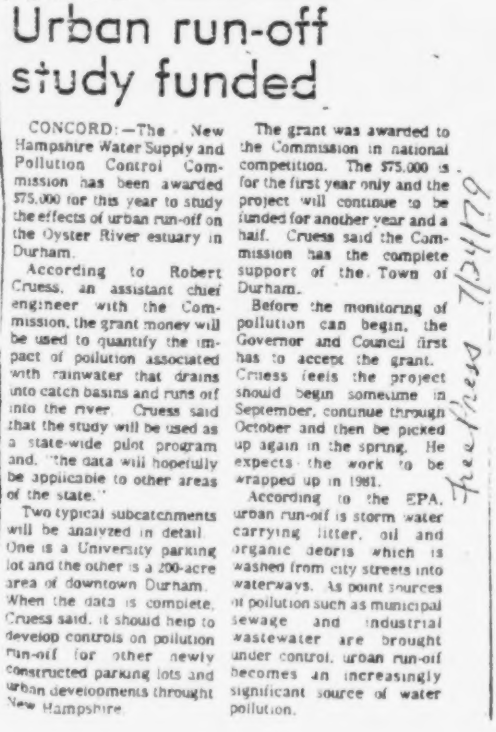
Hampton Union 7/25/79



BRIEFS

The U.S Environmental Protection Agency has awarded a total of $319,700 to study the effects of urban run-off on three New England waterways. The N.H. Water Supply and Pollution Control Commission will receive $75,000 for a project on the Oyster River estuary in Durham to determine cost-effective urban runoff controls which can be applied to a statewide permitting program. Two typical subcatchments will be analyzed in detail, one a parking lot and the other a 200 acre institutional/commercial/residential area. The impacts of the controls will be investigated through computer modeling.

Exeter News-Letter 7/25/79



Urban run-off study funded

CONCORD:—The New Hampshire Water Supply and Pollution Control Commission has been awarded $75,000 for this year to study the effects of urban run-off on the Oyster River estuary in Durham.

According to Robert Cruess, an assistant chief engineer with the Commission, the grant money will be used to quantify the impact of pollution associated with rainwater that drains into catch basins and runs off into the river. Cruess said that the study will be used as a state-wide pilot program and, "the data will hopefully be applicable to other areas of the state."

Two typical subcatchments will be analyzed in detail. One is a University parking lot and the other is a 200-acre area of downtown Durham. When the data is complete, Cruess said, it should help to develop controls on pollution run-off for other newly constructed parking lots and urban developments throught New Hampshire.

The grant was awarded to the Commission in national competition. The $75,000 is for the first year only and the project will continue to be funded for another year and a half. Cruess said the Commission has the complete support of the Town of Durham.

Before the monitoring of pollution can begin, the Governor and Council first has to accept the grant. Cruess feels the project should begin sometime in September, continue through October and then be picked up again in the spring. He expects the work to be wrapped up in 1981.

According to the EPA, urban run-off is storm water carrying litter, oil and organic debris which is washed from city streets into waterways. As point sources of pollution such as municipal sewage and industrial wastewater are brought under control, urban run-off becomes an increasingly significant source of water pollution.

Free Press 7/26/79

The State of New Hampshire

Water Supply and Pollution Control Commission
Prescott Park
P. O. Box 95 — 105 Loudon Road
Concord 03301

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LINDSAY M. COLLINS, P. E.
Director of
Municipal Services

August 13, 1979

Mr. George Crombie, Director
Public Works Department
Town Office
13 Newmarket Road
Durham, New Hampshire 03824

Dear Mr. Crombie:

This letter is written in confirmation of our telephone conversation of August 10, 1979. Please be informed that the New Hampshire Water Supply and Pollution Control Commission has received a grant amendment for the study of urban runoff in Durham, New Hampshire. A copy of a letter addressed to Mr. William A. Healy, Executive Director of the New Hampshire Water Supply and Pollution Control Commission, from Mr. William R. Adams, Jr., Regional Administrator for the Environmental Protection Agency, Region I, confirming the award of the grant is enclosed. The award of the grant was subject to completion of a satisfactory work plan. The Environmental Protection Agency's memo from Mr. William P. Somers to Mr. Roger F. Duwart, copy also enclosed, will confirm the acceptance of the work plan.

Please be informed that appropriation of the grant funds is dependent upon the acceptance of the grant by the State of New Hampshire Governor and Council. Upon approval by the Legislative Fiscal Committee, the grant acceptance is scheduled for the August 29, 1979 Governor and Council meeting. Acceptance of this grant by the Governor and Council is anticipated by the Commission staff.

At this time I would like to thank you for your cooperation with us in developing the work plan. In addition, I anticipate meeting with you in the near future in order to discuss, in detail, the implementation of the study.

Sincerely,

Paul J. Cavicchi
Senior Sanitary Engineer
Permits & Surveillance Division

PJC/bb
Enclosures
cc: Michael P. Donahue, P.E.
w/enclosures

C-2

The State of New Hampshire

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AND CHIEF ENGINEER

Water Supply and Pollution Control Commission
P.O. Box 95 - Hazen Drive
Concord, N.H. 03301

April 14, 1980

The Reverend Frederick Pennett
Catholic Student Center
Madbury Road
Durham, New Hampshire 03824

Dear Father Pennett:

As discussed at our meeting last Friday, April 11th, we would appreciate your permission to locate a small housing structure on the northwest corner of the Catholic Student Center property. The dimensions of the structure will be 2x2x4 feet, constructed of plywood in a shed-type fasion and painted New Hampshire green.

The structure will have quite expensive water quality sampling instrumentation used to determine the quality of Petty Brook, particularly after storm events. To discourage potential vandals, a floodlamp will be placed on the telphone pole next to the proposed structure location.

Water quality data from Petty Brook will be used along with data obtained from other sampling locations in Durham to characterize stormwater runoff from this mixed commercial, institutional, and residential area.

With your permission, we would like to install the structure during the week of April 21, 1980. The expected duration is one and one-half to two years.

Sincerely,

Paul L. Heirtzler, P.E.
Director, Permits & Surveillance

PLH/PHO/bb

Church of St. Thomas More
Catholic Student Center

P.O. Box LL • Madbury Road • Durham, New Hampshire 03824

APR 21 1980
WATER SUPPLY &
CONTROL
COMMISSION

April 16, 1980

Mr. Paul L. Heirtzler, P.E.
Director, Permits and Surveillance
Water Supply and Pollution Control Commission
P. O. Box 95 - Hazen Drive
Concord, New Hampshire 03301

Dear Mr. Heirtzler:

Thank you for your letter of April 14, 1980. This will confirm our agreement of April 11th, allowing your commission to erect a small housing structure on the northwest corner of the Student Center property. We understand the dimensions of the structure will be 2x2x4 feet, constructed of plywood and painted green.

We appreciate you putting the flood lamp on the telephone pole next to the proposed structure. We presume that any vandelism to the structure will be the responsibility of your commission.

We look forward to the improvement of Petty Brook which will be made by studies such as yours. You certainly have our permission to install the structure during the week of April 21, 1980. We understand that the expected duration of your project is one and one-half to two years.

Sincerely,

Frederick J Pennett

Rev. Frederick J. Pennett, Jr.
Catholic Chaplain
University of New Hampshire

FJP/vg

The State of New Hampshire

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Deputy Executive Director and
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Water Supply and Pollution Control Commission
Hazen Drive — P.O. Box 95
Concord, N.H. 03301

RECEIVED
MAY 8 1980
N. H. WATER SUPPLY &
POLLUTION CONTROL
COMMISSION

May 2, 1980

Mr. Samuel Tamposi, Jr.
2 Auburn Street
Nashua, New Hampshire 03060

Subject: Durham Shopping Center, Durham, New Hampshire

Dear Mr. Tamposi:

As per our telephone conversation of May 1, 1980, I am formally requesting your permission to allow us to install two slotted drains in the parking lot of the Durham Shopping Center. A description of our project follows.

In cooperation with the Environmental Protection Agency, the University of New Hampshire, and the Town of Durham, we are studying the characteristics of urban runoff. We have proposed four sampling stations which will allow us to study runoff from different land uses. Our station is adjacent to the Durham Shopping Center.

Because of the size of the Shopping Center, the number of storm drain inlets, and the limited amount of flow monitoring equipment available, we have decided to try and isolate one portion of the lot for study. The enclosed sketch will help to illustrate the study area.

In order to isolate the area we will have to install two slotted drains, each approximately twenty feet in length. The drains will be anchored in concrete so they will not come loose and will be flush with the existing pavement surface. The slots are bicycle proof. In addition to aiding our study, the drains will improve parking lot drainage during heavy storms.

The entire cost of materials and installation will be provided by this agency. Installation will be such that traffic will not be impeded. Our target date is the week of May 12. It has not been determined at this time if work will be contracted out or if Town forces will be used. If you have any preference in local contractors, please advise.

Mr. Samuel Tamposi, Jr.
May 2, 1980
Page Two

Finally, as you suggested, a request approval/non-approval is provided at the end of this letter. Two copies are provided, please keep one copy for your files.

If you require any additional information, please do not hesitate to call or write this office. Your cooperation is truly appreciated.

Sincerely,

Paul L. Heirtzler

Paul L. Heirtzler, P.E.
Director, Permits & Surveillance

PLH/bb
cc: Mr. George Crombie, Director of Public Works
Town of Durham, New Hampshire
Enclosure

- - - - - - -

I (approve) (~~do not approve~~) the above noted request.

Signature

5/6/80
Date

The State of New Hampshire

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Water Supply and Pollution Control Commission
Hazen Drive — P.O. Box 95
Concord, N.H. 03301

March 23, 1981

Mr. Craig Sturken
General Office
Shop N Save
North Hampton, New Hampshire 03862

Dear Mr. Sturken:

In reference to the Commission's study of stormwater runoff from the parking lot at your Durham store, we wish to express our thanks for your cooperation over the past several months and request additional assistance throughout the coming summer.

As previously discussed, it is necessary to characterize the nature of this runoff in terms of potential pollutants before any control technology is implemented to abate anticipated water quality problems. To date, we have not collected enough data for accurate characterization. For this reason we would appreciate continued handpicking of parking lot debris rather than use of the vacuum-type cleaner.

I have recently spoken with the Durham store Manager and understand that handpicking is more labor-intensive and necessarily less effective. Please be assured we fully appreciate the inconvenience involved and are thankful for the cooperation received in the past. Also, please understand that data collected during the "no-vacuum" condition are vital to the outcome of this study.

Along another vein, the Durham store Manager has brought to my attention recent repair work to the shopping mall rooftops. Since the application of tar sealant may have altered the runoff pattern from the rooftops, we must once again survey the roof area contributing to our study site. As in the past, we would like to gain rooftop access via the service entry in the rear of the supermarket.

In closing, we at the Commission feel certain that the results of this study, along with others throughout the nation, will prove mutually beneficial in providing aesthetically pleasing urban-type areas and improved water quality. Cooperation received from Shop N Save and several other involved interests has, and will continue to maximize potential benefits from this endeavor.

Truly yours,

Paul H. Oakland
Aquatic Biologist
Permits & Surveillance Division

PHO/bb
cc: Mr. Paul L. Heirtzler, Project Officer, Durham Urban Runoff Program

APPENDIX D
LITERATURE REVIEW

I. LITERATURE REVIEW

Urbanization of a watershed is characterized by the covering of the land surface with impervious material, in the form of paved roads and parking lots, buildings and sidewalks. This trend has a definite impact on stormwater runoff, in both quantitative and qualitative terms.

Effects of Urbanization on Runoff Quantity

Hydrologically, there are several factors which affect the flow of runoff from a watershed. Volume is a function of the amount of rainfall and retention of flow, the latter determined by soil infiltration, interception of rainfall by vegetation, and surface depression storage. The rate of runoff, or travel time, is primarily dependent upon the slope, flow length, depth of flow, and roughness of the flow surface. Peak runoff flow is affected by both the volume and the rate of runoff, as well as the area of the watershed, distribution of rainfall within a storm, and numerous other factors.

When a watershed is covered, to some degree, with impervious material, the result is a decrease in soil infiltration and interception by vegetal cover, and increased flow rates over the land surface (Soil Conservation Service, 1975). The combined effect of these factors is a significant increase in peak discharge, creating possible flood hazards and "shock-loading" of the receiving waters with pollutants contained in the runoff.

Many empirical formulas have been developed for the prediction of runoff flows from small watersheds. Among the most commonly used, due to their simplicity, are the Rational Formula (Mulvaney, 1850), the Runoff Curve Number Procedure (Soil Conservation Service, 1968), and the Unit Hydrograph Method (Sherman, 1932).

The Rational Formula is

$$Q = C\ I\ A \qquad \text{(Eq. 1.1)}$$

where Q is the peak discharge in cfs, C is a dimensionless runoff coefficient, I is the rainfall intensity in inches/hour, and A is the drainage area, in acres. The runoff coefficient represents the fraction of rainfall that contributes directly to runoff. Values range from 0 to 1, with the higher values typically representing increased imperviousness. The Rational Formula does not provide for computation of total runoff volume.

The Runoff Curve Number Procedure, or Soil-Cover-Complex Method, is a Soil Conservation Service method (1968) for estimating the total runoff from a storm event in a given watershed. The equation is

$$Q = (P - 0.2S)^2/(P + 0.8S) \qquad \text{(Eq. 1.2)}$$

where Q is the runoff in inches, P is the total rainfall in inches, and S is the potential abstraction in inches. Potential abstraction, the portion of rainfall that does not contribute to direct runoff, is defined by the runoff curve number, CN, as

$$S = (1{,}000/CN) - 10 \qquad \text{(Eq. 1.3)}$$

The curve number is related to soil and cover conditions (including antecedent moisture), and has been modified for urban watersheds (Soil Conservation Service, 1975) to also incorporate percent impervious cover. Miller and Viessman (1972) also modified the soil-cover-complex equations for rainfall events of less than two inches, in urban areas with 35 to 80 percent impervious cover.

The Unit Hydrograph (Sherman, 1932) is a method which utilizes measured storm hydrographs for a watershed to estimate the hydrographs for different storms of the same duration. By applying principles of superposition, it can also be used to generate hydrographs for storms of different durations. Implicit in this method is the assumption that there is no temporal or spatial variation on rainfall throughout the watershed. Although the hydrograph model includes functions for runoff lag and peak discharge, it does not provide a means of determining the total quantity of runoff.

It must be noted that predictions from any of the formulas described here are approximate. Major applications are for areas where sufficient rainfall or runoff data are unavailable, or for predicting changes in runoff flows under future development.

The amount of precipitation that occurs in an urban area is obviously a controlling factor in the amount of runoff that will result. For some urbanized areas, the urban environment itself may have an effect on the occurrence of rainfall in the area. Overton et al. (1978) report a theory proposed by Barkdoll (1975) and Betson (1976) that a weather modification effect may be occurring in the area around Knoxville, Tennessee. Surface heating from the city may produce convection currents which transport aerosols from local power plant emissions into the upper layers of clouds. The result is thought to be a larger than normal amount of rainfall occurring in the urban vicinity.

Changnon et al. (1976) found that the urban-industrial complex, under certain conditions, does provide a favorable site for rainfall initiation. An increase in the frequency of precipitation over certain areas may be caused by thermodynamic effects which induce cloud formation and the enhancement of precipitation due to the presence of nuclei-providing pollutant particles.

Thus, not only does the urban environment increase the amount of runoff from its land area by inhibiting infiltration and evapotranspiration, but in some cases, it may increase the amount of rainfall producing runoff.

Effects of Urbanization Runoff Quality

Bulk Precipitation Quality

It is commonly acknowledged that urbanization has a detrimental effect on air quality. Most of the pollutants that enter the air from auto exhaust, burning of fuels, industrial processes, etc., either settle back to earth as particulate dustfall, or are washed out in precipitation. The quantity, chemical composition, and size of the particles are determined by the numbers, types, and proximity of sources, extent of precipitation, topography and air movement patterns (Johnson et al., 1966).

In terms of runoff quality, the difference between dryfall and precipitation is insignificant in that both contribute pollutants to the runoff. Loehr (1974), in analyzing precipitation data published in the literature, noted that a distinction was not often made between sources, therefore he treated all reported values as bulk precipitation. Trends in the data indicated that sulfate concentrations in bulk precipitation have increased in recent years, probably due to industrial processes.

The phenomenon of acid rain is an important issue in the northeastern United States. One of the most often cited studies on the subject is that of Likens and Bormann (1974), conducted at the Hubbard Brook Experimental Forest in north-central New Hampshire. Having monitored the chemistry of precipitation for more than ten years, they reported that the pH of rain in most of the Northeast is considerably lower than would be expected under natural conditions. The flow weighted mean pH of rainfall at Hubbard Brook was 4.03, as opposed to a normal value of 5.7. The mean pH at other sites in the Northeast were similar. Values of pH as low as 2.1 have been reported for individual storms.

Johnson (1979) investigated the effects of acid rain on the streams in the Hubbard Brook study area. Interestingly enough, the pH of the streams was not acidic, apparently the result of rapid neutralization by basic aluminum salts and biologic matter contained in the soil zone. Johnson alleges that stream water from low-order basins is more apt to be acidic and rich in aluminum than older stream and ground water sources in higher-order basins. The implications of this study with respect to urban runoff are significant; by covering over the soil with impervious material, we may also be inhibiting the natural chemical reactions which would otherwise mitigate the impact of acid rain on New England waters.

Betson (1978), in a study of three watersheds of varying land use in Knoxville, Tennessee, related bulk precipitation to streamflow quality on an annual input-output basis. The results of the study indicated that atmospheric sources accounted for high percentages of most constituents in the streamflow. The bulk precipitation concentrations recorded at Knoxville were comparable to those found elsewhere (see Table 2, page). Betson suggests that in rural areas, much of the atmospheric fallout is retained on vegetation until it is washed off by rainfall. Since little overland flow actually occurs in such areas, the watershed serves as a sink for some of the constituents.

Snow which remains on the ground for several days after falling may serve as a medium for subsequent dustfall to adhere to, as well as a retainer of constituents of the initial precipitation. Pierstorff (1978) investigated the presence of pollutants in snow collected from the streets of Durham, New Hampshire, and dumped at two sites adjacent to the Oyster River. It was estimated that a total of 240 tons of total solids, 117 tons of chlorides, 13.3 tons of COD, and 0.16 tons of lead were contained in snow dumped at the sites over a two year study period (1976-1977). Analyses of natural snow indicated that most of the constituents were accumulated between the time of precipitation and removal to the dump sites. Evidently, the primary source of the pollutants was atmospheric fallout, with the exception of the chlorides, which probably were the result of road salting.

Newton et al. (1974) studied snow in Oklahoma that had remained on the ground for six days at sub-zero temperatures. Lead concentration in the snow along roadsides was 5.5 mg/l, which the authors attributed to exhaust from passing traffic. The association of lead concentrations in runoff and traffic density will be discussed in a later section.

Road Sediment

Street surface contaminants may be defined as any materials found on streets which are capable of being washed off during a normal storm event (Sartor et al., 1974). In addition to the atmospheric dryfall discussed in the previous section, these contaminants may include litter, organic debris, oils and sands from highway maintenance operations, animal wastes, etc. The pollutants accumulate on urban streets until they are removed by wind, street cleaning processes, or stormwater runoff.

Bradford (1977) performed statistical analyses on data reported in the literature prior to 1972, on the subject of dust and dirt accumulation on street surfaces. Some watershed outfall studies (sampling of actual runoff) were included, but did not differ significantly for most parameters from studies where just the road sediments were examined. The analyses failed to show any significant trends, other than the fact that samples were generally high in contaminants. Bradford suggested that the variability of the data with respect to sampling locations and methodology might explain the lack of statistical significance.

Sartor et al. (1974) collected and analyzed street surface contaminants from several cities throughout the country. Quantities of contaminants were found to vary widely, but were generally related to the time since the last cleaning, either by sweeping or runoff. The contaminants were found to be composed primarily of inorganic sand or silt. It was determined that most of the associated pollutants were contained in the fine solids portion of the material, which are the least apt to be removed by common street sweeping practices. When related to land use, streets in industrial areas were found to contain the greatest quantities of pollutants, with a weighted mean of 2800 pounds per curb mile. Residential streets had a weighted mean of 1200 pounds per curb mile, while commercial streets were significantly less polluted, with 290 pounds per curb mile of contaminants.

Whipple et al. (1974) criticize studies of the type performed by Sartor et al. (1974) and most of the ones reviewed by Bradford (1977), where no actual runoff samples were collected. They assert that studies made of just road sediments or mud in catchbasins can grossly underestimate pollutant loadings in runoff. This may be true, but studies such as Sartor's et al. do provide valuable information concerning the relative influences of land use on runoff quality. Interpretation of such studies must still be made bearing in mind that street sediment is not the sole source of pollutants in runoff.

Variables Influencing the Quality of Runoff

In the statistical study cited earlier, Bradford (1977) lists some of the dependent and independent parameters of storm runoff that have been identified in past studies. Climate is listed as the primary independent variable, with season of the year and land use effects also noted as being important. The dependent variables given are the quantity of runoff and relative concentrations of various pollutants. Bradford notes that average daily traffic cannot be correlated effectively with pollutant concentrations, as in some cases the traffic may actually blow pollutants away. Attempts to relate the independent parameters listed to some of the key dependent variables were unsuccessful in the studies he cited. Others, however, have been able to relate pollutant loads to variables such as land use, as has already been shown by Sartor et al. (1974).

Whipple et al. (1974) reported that pollution in runoff from an urban area varies primarily with the concentration of population, commerce and industry, and not so much with catchment area. In addition, pollution resulting from any one storm varies with the season of the year, time since the last rainfall (antecedent precipitation), effectiveness of street cleaning, and the general hydrologic characteristics of the event.

As cited by Overton (1978), Barkdoll (1975) listed antecedent dry weather, along with the intensity and duration of runoff, contaminant removal mechanisms, and land use as the primary factors governing the pollutant loadings in runoff. He developed a deterministic model for use in analyzing the relationship between dustfall, storm runoff, and water quality. He also used a parametric model to relate the average concentration of a contaminant during a storm event, total mass of the contaminant available for removal, runoff volume, and the amount of rainfall necessary to remove 63.2 percent of the accumulated contaminant. For further descriptions of these models, the reader is referred to Overton's report. Overton used data collected from four Knoxville, Tennessee, watersheds, differing in land use and hydrologic characteristics, to test Barkdoll's models. The results indicated that the deterministic model is too simplistic for adequate representation of the runoff process. However, the parametric model was found to be useful in assessing the sources, magnitude, and variation in pollutant loadings from different land uses and geological types. It was concluded that a larger data base is required for accurate evaluation of such models.

Other storm runoff models which have been developed include EPA's Stormwater Management Model (SWMM), Nonpoint Source Pollutant Loading Model (NPS), Agricultural Runoff Management Model (ARM), and the Water Resources Engineers/U.S. Army Corps of Engineers' STORM model. The reader is referred to Field et al. (1979) and Field and Cibik (1980) for reviews of the literature on these and other models.

Zison (1980) describes ARM as the model type which attempts to mechanistically simulate water chemistry of the soil and runoff, while STORM, SWMM and NPS assume the mass emission rate of each pollutant to be linearly related to sediment mass emission rate. In an effort to develop potency (weighting) factors for relationships of the latter form, Zison conducted a statistical study in the nature of relationships between runoff sediment loads and concentrations of other constituents, as taken from established data bases. Results of his study indicate that suspended solids loading correlates with runoff quality best when other factors such as antecedent rainfall, time since the start of the storm, cumulative rainfall since the start of the storm, and time since the last chemical application (specifically in agricultural watersheds) are included. The potency factors developed in the study, and recommendations for their application in the various models, are described in the EPA document by Zison.

Rimer et al. (1978) collected runoff data from different land use types in the Piedmont Region of North Carolina, for use in the calibration of the SWMM model previously referred to. They found that phosphorus and lead concentrations were closely associated with the level of suspended solids. Within seven categories of land use, ranging from low activity rural to urban watersheds, the level of nonpoint source pollution generally increased with the extent of imperviousness. The exception to this trend was a central business district which, in spite of a high degree of impervious cover, was not a major contributor of pollutants. It was suggested that the reasons for the business area's relative cleanliness were the lack of land-disturbing activity (e.g., construction) and the effects of street sweeping. This may also explain why Sartor et al. (1974) found significantly lower amounts of street surface contaminants in commercial areas than in industrial or residential areas.

Helsel et al. (1979) measured concentrations of seven metals contained in runoff from nineteen subbasins, of homogeneous land use, within the Occoquan and Four-Mile Run watersheds near Washington, DC. They reported significant differences between land uses with respect to lead, manganese, iron, copper, chromium, and zinc. Average concentrations of iron and manganese were higher in agricultural runoff than in runoff from forested land. The authors attributed this trend to greater sediment losses in the agricultural areas, since the two metals compose most sediment oxide coatings. Iron, zinc and copper concentrations were greatest in urbanized areas. In nonlinear relationships, lead, zinc and copper correlated well with traffic and percent impervious cover. An inverse correlation was found between iron and percent imperviousness, again attributed to soil losses from agricultural watersheds. Cadmium was not found in detectable levels in any of the basins.

Griffin et al. (1980) performed studies of runoff quality variations, also within the Occoquan and Four-Mile Run watersheds. Analyses were for parameters other than the metals studied by Helsel et al., and included suspended solids, COD, and several species of nitrogen and phosphorus. Sixteen subbasins were categorized according to their extent of urbanization, as measured by percent impervious cover. Nonparametric methods of statistical analysis were used, and indicated a monotonic increase in pollutant yield with increased percent imperviousness.

During the spring and summer of 1976, Polls and Lanyon (1980) investigated runoff quality from sixteen watersheds of homogeneous land use in the metropolitan Chicago area. Stream flow in the watersheds was considered representative of storm flow only, as there were no point discharges or combined sewers in the area. Table 1 summarizes the results of this study. The greatest variations between land uses were in the concentrations of total solids, suspended solids, and volatile suspended solids. As can be seen from the reported

Table 1

Comparison of Mean Concentrations[1] of Selected Parameters for Nonpoint Runoff from Homogeneous Land Uses (after Polls and Lanyon, 1980)

Land Use or Source	BOD$_5$	COD	Total Solids	Total Sus-pended Solids	Ammo-nium Nitrogen	Nitrite-Nitrate Nitrogen	Soluble Phos-phorus
Untreated wastewater[2]	140	329	862	199	14.4	0.5	4.31
Secondary-treated wastewater	11	96	617	11	9.1	3.13	1.29
Forest	2	--	1046	34	0.2	0.2	0.04
Agricultural	13	122	1136	762	0.4	4.2	0.27
Light industrial	14	78	634	302	0.4	1.2	0.19
Commercial	22	168	1242	386	0.5	1.6	0.24
Highway	14	128	2097	266	0.4	1.1	0.07
Single-Family	17	104	818	513	0.5	1.4	0.14
Multi-Family	16	117	1074	797	0.5	1.1	0.23

[1] Concentrations are in mg/l.

[2] A combined mean value for three MSDGC sewage treatment plants, 1977.

values, agricultural and multi-family residential land uses had the highest suspended solids concentrations, and the highway the least. The opposite was true for total solids. The highway watershed also contributed the least soluble phosphorus. As would be expected, due to fertilizer application, agricultural runoff was highest in nitrite-nitrate nitrogen. The greatest overall concentration of pollutants occurred in the commercial area, while the forested sub-basin contained the least.

Collins and Ridgway (1980) reported that total organic nitrogen, ammonia nitrogen, total phosphorus, lead, iron, and BOD loads in runoff are all related to the mass of suspended solids, while nitrate, dissolved orthophosphate, chloride, total dissolved solids, oil and grease, and fecal coliforms are related to the mass of runoff alone. Their conclusions were derived from sampling and flow measurement in separate storm sewer outfalls during storms on five watersheds in southeastern Michigan. In terms of the association of phosphorus and lead with suspended solids, these findings corroborate those of Rimer et al. (1978).

Bryan (1972) agrees that the majority of the pollutants in urban runoff are indeed contained in the suspended solids fraction (as is the underlying assumption of most of the models discussed by Zison, 1980) and thus are more easily removed than the pollutants in wastewater. In his study of urban runoff in Durham, North Carolina, data indicated that lead yield is related to land use and the increased traffic density associated with commercial development. Lead yields from residential areas were half those from commercial developments. Data from the North Carolina study were insufficient to support good correlations between parameters, and no obvious effects of antecedent conditions on yield were in evidence.

Whipple et al. (1978) summarized the individual research of five different institutions on the subject of nonpoint source pollution. Generally, the results of the various studies indicated that high BOD loadings occur in runoff from heavily developed areas. Phosphate loadings also increased significantly with increased urbanization, as did sediment transport. High coliform counts were recorded in both the residential and the commercial study areas. The authors agree that there may be a relationship between phosphate, sediment, and heavy metal loadings and flow, but that is not a linear one.

In another study, Whipple et al. (1978b) determined pollutant loadings in the runoff from two storm-drained watersheds in a multiple family housing development in Hightstown, New Jersey. Total loadings of BOD, lead and zinc increased proportionately with flow, while those of ammonia nitrogen, nickel, copper and chromium increased at a slower rate. Phosphorus decreased with flow, as it did in previous studies by Whipple et al. (1974) on the Saddle River in Lodi, New Jersey. However, unlike that study, total sediment loadings in Hightstown did not even increase at a rate proportionate to the cumulative flow. The results of the Hightstown study indicate that, at least in terms of BOD and phosphorus, multiple family housing seems to generate more runoff pollution per housing unit than single family housing. Pollutant loads determined in this study are compared with those reported by other researchers (see Table 3, page 28), and further discussed in a later section of this report.

In a recent paper, Whipple et al. (1981) report on the differing effects that runoff from urban development has on the erosion of stream channels and banks. Twenty-five stream reaches were classified into categories of light, medium, and heavy erosion. Analysis of the characteristics relating to each category showed that densely developed areas correspond to greater erosion, and wide stream buffers of natural vegetation correspond to lesser erosion. No definite correlation was demonstrated between erosion and soil type or slope.

One of the earlier studies on the topic of urban runoff was accomplished by Weibel et al. (1966), who investigated stormwater quality in Cincinnati, Ohio. In runoff from urban areas there, suspended solids concentration was found to exceed that of raw sanitary sewage, with BOD, COD, and other parameters significantly less. However, it must be emphasized that these parameters may have significant impact even in low concentrations, due to the magnitude of flow and the effects of shock-loading. Part of Weibel's et al. (1966) study was a comparison of runoff quality from a 27 acre residential, light commercial part of the city to that from a 1.45 acre field of winter wheat. Concentrations in runoff from the rural area exceeded those in urban runoff for suspended solids, organic and inorganic nitrogen, and total hydrolizable phosphate. BOD, COD, and coliform concentrations in the urban study site were considerably higher than in rural runoff. Concentrations reported by Weibel et al. are listed in Table 2.

Bedient et al. (1980) recently conducted a study of water quality variations in a shallow, concrete-lined urban drainage channel. Developing pollutant loads for the one year study period, they found that

Table 2

Parameter Concentrations Reported in the Literature[a]

Study	BOD	COD	Total Solids	Suspended Solids	Fecal Coliform (MPN/100ml)	Total Phosphate	Ammonia Nitrogen	Nitrite and Nitrate	Chloride
(Bryan, 1972) Durham, NC Urban runoff	14.5	179	2730	--	30,000	0.58	--	--	12.6
(Colston, 1974) Durham, NC Urban runoff	--	170	1440	1223	23,000	--	--	--	--
(Weibel, 1966) Cincinnati, OH Rainfall	--	16	--	13	--	0.24	--	--	--
Urban runoff	17	111	--	227	50-76,000	1.1	--	--	19.8
Coshocton, OH Rural runoff	7	79	--	313	2-26,000	1.7	--	--	--
(Betson, 1978) Knoxville, TN Bulk precipitation	--	65	--	16	--	1.1	0.41	0.47	4.0
Commercial runoff	--	110	--	3200	--	0.6	0.1	0.7	8.6

[illegible]

Table 2 - continued

Study	BOD	COD	Total Solids	Sus-pended Solids	Fecal Coliform (MPN/100ml)	Total Phosphate	Ammonia Nitrogen	Nitrite and Nitrate	Chloride
(Holbrook et al., 1976) Atlanta, GA									
Rainfall	5	13	--	7	--	--	0.13	0.05	--
Urban runoff	9	40	--	287	6,300	--	0.18	0.25	--
(Collins and Ridgway, 1980) SE Michigan									
Urban runoff	9.3	40	--	163	8,000	0.48	0.21	0.90	85
(Whipple et al., 1974) Morristown, NJ Urban runoff									
March	2.87	--	--	74	--	--	--	1.2	--
August	4.4	--	--	36	--	--	--	2.9	--
(NHWSPCC, 1979) Concord, NH									
Urban runoff	53	161	--	134	23-240,000	--	1.0	0.89	12

*Concentrations are in mg/l unless otherwise noted.

stormwater contributes 96 percent of the total suspended solids and 25 percent of the total phosphorus annual loads for the study area.

Black (1980) intensively sampled runoff from a single thunderstorm on a mall parking lot in central New York. The storm event deposited 0.45 inches of rain with a 1.5 hour time period. Rainfall, surface runoff, subsurface runoff and streamflow samples were collected upstream and downstream of the parking lot. Reported high ammonia nitrogen content in the runoff was attributed to rainfall, rather than surficial sources. Increased temperature and decreased conductivity were recorded in the runoff stream, but returned to pre-storm levels within five hours. Concentrations downstream of the lot demonstrated a characteristic flushing/dilution sequence for nine constituents tested. Prestorm levels of those constituents were also restored within five hours.

The flushing/dilution sequence that Black (1980) refers to is a phenomenon noted by others studying urban runoff. Also referred to as a "first flush," it is characterized by high initial concentrations of a pollutant, with the peak concentration occurring before the peak runoff flow. The first flush may be attributed to an initial washing off of accumulated contaminants from the land surface. When storm events occur closely together, the first flush may be absent (Wullschleger et al., 1976). According to Griffin et al. (1979) and Helsel et al. (1979), suspended pollutants are more inclined to exhibit a first flush than soluble ones.

Whipple and Hunter (1977) refer to the flows from storm sewers and channels draining urban areas as being particularly flashy, with rapid changes in pollutant concentrations. They claim that pollutant loading may vary by three orders of magnitude within thirty minutes, with a strong first flush in evidence. Holbrook et al. (1976) also noted a strong first flush effect in combined sewer overflows in Atlanta, Georgia. Wilber and Hunter (1977) reported a first flush of heavy metals in the Saddle River in Lodi, New Jersey. However, they attributed it partly to the settling out of solids in storm sewers as flow tapered off.

It is evident from the studies cited here that the extent of urbanization of an area, reflected in either the land use or the percent of impervious cover, has a significant effect on the nature and amounts of pollutants contained in the runoff. Generally, the extent of pollution has been shown to increase with the degree of urbanization. Some exceptions may include a high level of inorganic nitrogen and suspended solids in agricultural runoff, with lower amounts of nitrite-nitrate nitrogen in heavily developed areas. It has also been demonstrated that a significant portion of the pollutants in runoff are associated with the suspended solids fraction of the stormwater. It appears that the relationships between parameters of pollution are complex, as they are dependent upon the influence of numerous independent variables.

Quantification of Pollutants in Urban Runoff

As is evidenced in the preceding sections, the urban environment contributes in various manners and degrees to the nature of pollutants found in runoff. In order to evaluate the impact of urban runoff on the aquatic environment of the receiving water, it is necessary to quantify specific water quality parameters.

Table 2 presents some of the runoff and bulk precipitation constituent concentrations reported by Bryan (1972) and others. Table 3 lists similar information in the form of daily loading rates. It should be noted that certain studies may report different values for concentration, but be similar in loading rates for the same parameters. Since many of the concentrations reported are those found in the receiving streams, the dilution factor involved may differ between studies. Loading rates, however, are not flow-dependent. Values represent the mass flux of pollutants occurring in a watershed, as related to land area, amount of precipitation, or increments of time.

Oxygen-Demanding Pollutants

One of the most important water quality parameters in a receiving water body is the dissolved oxygen concentration. Depletion of the dissolved oxygen supply can have a direct effect on the aquatic ecosystem, as well as the recreational and aesthetic uses of a water body. Pollutants contained in urban storm runoff can exert an oxygen demand as a result of two processes; the biochemical oxidation of organics by microbial activity (measured by BOD) and the immediate chemical oxidation of inorganic reduced compounds (measured as COD).

Since the COD test measures a more immediate oxygen demand than does the BOD test, a comparison of the two values can indicate the relative nature of the exerted demand. For example, Ammon and Field (1977) cite an average COD:BOD ratio of seven for urban storm runoff, and a ratio of two for secondary effluent. From a comparison of the two ratios, they conclude that "background" oxygen demand observed during dry weather is partly due to the residential effects of wet weather discharges.

Table 3

Pollutant Loads Reported in the Literature*

Parameter	Durham, NC Urban runoff (Bryan, 1972)	Hightstown, NJ Multi-Family runoff (Whipple et al., 1978b)	Morristown, NJ Urban runoff (Whipple et al., 1974)		Concord, NH Urban runoff (WSPCC, 1979)
			March	August	
BOD	147.9	120.0	154	38.7	150
COD	1,822	700	--	--	54º
Total Solids	27,780	--	--	--	--
Volatile Total Solids	3,014	--	--	--	197
Suspended Solids	--	2,107	3,960	3,350	951
Total Phosphate	5.92	--	112	13.5	--
Ammonia Nitrogen	--	10.1	21.1	--	3.2
Nitrite and Nitrate	--	11.4 (NO_3^-)	65.4	25.0	3.2
Chloride	128.2	--	--	--	26

*Loads are in lb/mi^2/day.

Heaney et al. (1979) cite a study for the EPA by Keefer et al. (1978) in which dissolved oxygen deficits were assessed as they related to storm runoff. One third of the 100 monitoring sites in and downstream of selected cities indicated at least a 60 percent probability of a higher than average dissolved oxygen deficit during storm flows. The minimum wet weather concentration was 1 to 1.5 mg/l less than the dry weather minimum, and remained so for several days.

Bryan (1972) sampled runoff from a 1.67 square mile urban drainage basin in Durham, North Carolina, for a total of thirty storms. Runoff was collected from the main channel of the basin, which had a base flow of less than 0.1 cfs, and a maximum storm flow of 700 cfs. To allow for the estimation of pollutant yield, the basin was characterized in terms of land area and population, length of slope of the drainage channel and land surface, and land use.

Bryan reported that the contribution of total organic matter from urban runoff equals or exceeds that of raw sanitary sewage. BOD concentrations ranged from 2 mg/l to more than 232 mg/l, with a flow-weighted mean of 14.5 mg/l. The COD concentrations reported ranged from 20 to 610 mg/l, and the flow weighted mean was 179 mg/l. As may be seen in Table 2, these values are similar to those found in Cincinnati runoff by Weibel et al. (1966). The daily loadings of BOD and COD for Durham, North Carolina, as estimated from the concentrations determined, are mentioned in Table 3.

Whipple et al. (1974) conducted a mass balance analysis of unrecorded pollutants in a 5.2 square mile drainage area of the Upper

Whippany River, in the vicinity of Morristown, New Jersey. Land use in the basin was 39 percent residential, 5 percent industrial, and 2 percent commercial, with the remainder being streets and vacant land. Studies were conducted during March and August (1972), in order to represent high and low flows respectively. Parameters concentrations are reported in Table 2, and daily loadings in Table 3. The mean BOD loading in Morristown was estimated to be 75.2 lb/sq mi/day (assuming that the March and August flows were actually representative of the extremes) a value considerably less than the 147.9 lb/sq mi/day reported by Bryan (1972). This difference can be attributed to the fact that the Morristown basin was three times the size of the Durham one, and somewhat less urbanized. When Whipple et al. compared the loads on a per person per day basis, the values were similar for the two basins.

A study of the characterization of stormwater runoff in Concord, New Hampshire, was recently completed by the New Hampshire Water Supply and Pollution Control Commission (1979). The study involved detailed monitoring of storm discharge in two areas considered representative of other developing areas in the state. The primary study area was a 225 acre watershed of institutional, commercial, and high density residential land use, serviced by a separate drain system. The secondary area was an 18 acre commercial shopping center, also drained by a separate storm drainage system. Seven storms of varying intensities were monitored at the primary site during the period from May to August, 1977 (see Tables 2 and 3). The BOD range found at the primary site was comparable to that reported by Weibel et al. (1966); however, the flow-wieghted mean concentration of BOD was considerably higher than the values reported by others. This is probably due to the fact that the runoff sampled in the Concord, New Hampshire, study was not diluted with dry weather flow. When compared in terms of daily loads (Table 3), the Concord results compare well with others.

Data for the secondary study area in Concord was limited to one storm. Loadings for that storm were lower than expected, possibly due to sampling error since the primary site exhibited low values for the same storm.

Solids

The solid material contained in stormwater may be divided into two categories: particulate (suspended) solids, and dissolved solids. Particulates are of specific concern in the analysis of storm runoff because they usually represent a large fraction of the total solids (Wullschleger et al., 1976). In addition, it is these solids which are most easily removed, either by natural settling processes, or by physical treatment processes such as screening, sedimentation, and filtration.

As mentioned previously, several authors have reported that many of the pollutants contained in runoff are associated with particulate solids (Bryan, 1972; Collins and Ridgway, 1980; Rimer et al., 1978). This relationship is of significant importance in the consideration of treatment alternatives.

Bryan (1972) reported that total solids loadings contributed by Durham, North Carolina, runoff exceeded those expected from raw sanitary sewage (Table 3). The suspended solids fraction of the load was not determined. In Cincinnati, Ohio, Weibel et al. (1966) found that the suspended solids fraction in runoff, at least in terms of concentration, also exceeded that of raw sewage. They noted that runoff from a rural watershed was significantly higher in suspended solids concentration than was urban runoff. Cóncentrations from the two watersheds were 313 mg/l and 227 mg/l respectively. As is shown in Table 2, these values are comparable to ones found in Michigan (Collins and Ridgway, 1980) and Georgia (Holbrook, 1976). Lower concentrations were reported in Concord, New Hampshire (NHWSPCC, 1979), while values an order of magnitude higher were determined in two Knoxville, Tennessee, watersheds (Betson, 1978) and on Third Fork Creek in Durham, North Carolina (Colston, 1974).

Suspended solids concentrations from the watersheds investigated by Polls and Lanyon (1980) (see Table 1) were also similar to those of Weibel et al. Agricultural and multiple family housing were the land uses with the highest contributions of this parameter. Whipple et al. (1978b) found similarly that runoff from multi-family housing was relatively high in sediment concentration.

Nutrients

The nutrients which receive the most attention in urban stormwater analyses are nitrogen and phosphorus. They are considered as pollutants because of their potential for stimulating entrophication and resulting in water quality degradation. Phosphorus especially is considered to be the most important limiting factor to general aquatic plant growth, specifically in its available phosphate form. Nitrogen is a necessary component of the life process of all plants and animals, although its availability to algal growth is limited to the inorganic forms of nitrate (NO_3^-), nitrite (NO_2) and ammonia (NH_3).

A number of difficulties are likely to be encountered in accurately assessing the nutrient contributions of urban runoff. Although many water bodies are analyzed during low flows to represent "worst" conditions, Whipple and Hunter (1977) have pointed out that the higher concentrations and loadings of phosphorus during higher flows (storm events) may actually represent a "worse" case. It has also been suggested (Loehr, 1974) that the concentrations and loads of nitrate are greatest in high flows.

According to Loehr, only 5 to 10 percent of the phosphorus applied in fertilizer is taken up by vegetation, while the rest is converted to insoluble forms and retained in the soil. This phosphorus may erode into the runoff stream as a suspended sediment. In its insoluble form, phosphorus may be measured in high concentrations, while relatively little of it is actually available to create an impact on the receiving water.

Cowen and Lee (1976) performed tests in Madison, Wisconsin, to determine the actual availability of total phosphorus in runoff. Available total phosphorus is related to the availability of each form in which it occurs:

$$\text{Available Total P} = (\text{Soluble P} \times \text{Percent Soluble P available}) + (\text{Particulate P} \times \text{Percent Particulate P available}) \qquad \text{(Eq. 1.4)}$$

Based on the assumption that all of the soluble P is converted to orthophosphate, it may be considered readily available to algae. Cowen and Lee estimated that 40 percent of the total P in runoff is in particulate form, then conducted bioassays with actual runoff samples. They concluded that an average of 30 percent of the particulate P is in available forms. Forms of phosphorus in runoff from different land uses were also compared and determined to be similar.

The nitrogen contained in fertilizer is oxidized to nitrate, a soluble form which moves easily in either ground or surface water systems. However, since it moves slowly, much of the nitrogen is used up by plants. The presence of nitrogen in the runoff must be interpreted with caution, as Whipple and Hunter (1977) note, due to the dynamic processes of nitrification common in many streams.

Cowen et al. (1976) have stated that since organic forms of nitrogen are readily available for algal growth in lakes, the availability of total nitrogen in runoff is dependent upon the relative amount of total organic nitrogen, and the availability of the organic N to algae:

$$\text{Available Total N} = \text{Inorganic N} + (\text{Organic N} \times \text{Percent Organic N available}) \qquad \text{(Eq. 1.5)}$$

The determining factor in the availability of organic N is the rate at which it is mineralized to organic form. On the basis of tests on Madison runoff, Cowen et al. determined that at 21°C, an average of 70 percent of the total N was in available form. They emphasized the importance of considering the mineralization of organic nitrogen in the determination of stormwater impacts.

Bacterial Contamination

Total and fecal coliform, and fecal streptococci are measured as indicators of pathogenic organisms present in aquatic systems. Excess concentrations of bacterial indicator organisms in storm water runoff may have impacts on water supply and recreational use of the receiving water body. Commonly used standards for recreational use of a water are a total coliform density of less than 1000/100ml and a fecal coliform density of less than 200/100ml (Heaney et al., 1979).

In order to distinguish between sources of fecal contamination, the fecal coliform/fecal strep ratio (FC/FS) may be determined. A value of less than one implies that fecal contamination is from animal sources, while a ratio of greater than four implicates human fecal contamination. Values between one and four are subject to interpretation.

Davis et al. (1977) investigated the bacterial content of runoff from a rural, developing area near Houston, Texas. Indicator bacteria and three species of bacterial pathogens were quantified, as well as their chlorine or ozone demand. Without exception, all groups of the bacteria studied exhibited a first flush, peaking prior to the hydrograph peak. Fecal coliform and fecal strep values were higher in more developed areas than in the primary rural site, and their numerical ratios were similarly related. Diurnal variations were determined to create great fluctuations in bacterial densities, even in dry weather. Therefore, the authors cautioned that grab samples collected in other studies must be evaluated with respect to the time of sampling. Multiple regression analysis performed on the data led to the conclusion that streptococci are the most useful group in evaluating stormwater quality.

Whipple et al. (1978) noted high coliform counts in runoff from both residential and commercial areas. Weibel et al. (1966) reported coliform densities greater than 2900/100 ml in 90 percent of the urban runoff samples from Cincinnati, Ohio, and over 1000/100 ml in 40 percent of the samples from a rural watershed near Coshocton, Ohio. Fecal coliform organisms exceeded 400/100ml in the urban samples, and 22/100ml in rural runoff. The FC/FS ratios for both sites were less than unity, indicating non-human sources.

Bryan (1972) found mean fecal coliform densities of 30,000/100 ml in North Carolina. The FC/FS ratio was less than one. Bryan's value is sixty times that reported by Weibel et al. in the Ohio study. In southeast Michigan, fecal coliform densities reported by Collins and Ridgway (1980) were 8,000/100 ml.

In an urban sector of Concord, New Hampshire (NHWSPCC, 1979), coliform densities from seven runoff events ranged from 2300/100 ml to more than 240,000/100 ml for total coliform, and from 23/100 ml to over 240,000/100 ml for fecal coliform. These ranges span the values reported in other studies, indicating the amount of variation which can occur in coliform densities within a single study. As with the other studies cited, FC/FS ratios in Concord were less than unity, ruling out human fecal contamination as a possible source.

Heavy Metals

Many heavy metals are essential to life processes at low concentrations, while at higher concentrations they may become toxic. In runoff, heavy metals occur from traffic activity, atmospheric fallout and washout, metal plating, soil erosion, vegetative material, pesticides, chemical spills, and natural background sources (Ammon and Field, 1979). Some of the heavy metals on EPA's priority pollutant list which are known to be toxic to aquatic life in low concentrations and with relatively short exposure are listed by Field and Ammon. They include: antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc.

Water quality criteria established by federal and state authorities estimate the concentrations of constituents in ambient water which represent the maximum values to ensure protection of a specified water use. However, as Ammon and Field (1979) point out, many of the metals in runoff occur as particulates, which settle out and accumulate in the bottom sediments. Such impacts are not reflected in water quality criteria. Concentrations in the receiving water column after metals settle out are apt to be less than a normal dilution would imply, while the metals continue to accumulate in bottom sediments. As with the nutrients discussed previously, interpretation of metals concentration data should only be made bearing in mind the fraction of pollutants which are actually available to impair water quality.

Wilber and Hunter (1977) investigated the accumulation of heavy metals in the bottom sediments of the Saddle River, at sites upstream and downstream of Lodi, New Jersey. Analyses were made of precipitation, runoff, and tributaries in order to delineate sources. Benthal deposits were analyzed from three transects of the river to assess the fate of heavy metals entering the stream. The findings of the study indicated that the relative contributions of rainfall were insignificant. Lead, zinc, and copper comprised 90 to 98 percent of the heavy metals contained in the runoff and tributaries, with lead and zinc representing 89 percent of the three species. Mass balance analysis of the river was negative for metals, indicating their conservative nature. Presumably, the difference in mass flux between the upstream and downstream sites represents settled particulates. Concentrations of metals in the river sediments collected in this study were quite variable.

In a later study, Wilber and Hunter (1979) continued their investigations of metals in the Saddle River. Significant enrichments were found in the lower portion of the river, as compared to sediments in the upper reaches. Concentrations were also noted to be higher in the larger sediment fractions than in smaller ones, probably due to decreased scour and transport mechanisms where large sediment deposits occur. Tables 4 and 5 list heavy metals concentrations and loads repsectively, as reported by Wilber and Hunter and other researchers. Values are generally similar, except the higher loads reported in an industrial portion of the Saddle River (Whipple et al., 1978) and loads less than the norm reported in Concord, New Hampshire (NHWSPCC, 1979).

Whipple et al. (1978), in their summary of research done by five institutions, noted that the concentrations of heavy metals found in the Saddle River (New Jersey) were comparable to those found in several Virginia watersheds. They also verify the claim made by Ammon and Field (1979) that most metals in runoff occur in particulate form, settling out at least temporarily in the stream bed.

Bradford (1977) noted in his survey of data reported in the literature that the Northeast demonstrated unexpected below average concentrations of chromium, lead, nickel and zinc. The sample cities considered were all typified by heavy industrialization. However, as previously noted, Bradford's study was of street surface contaminants rather than actual runoff. Differences in climate, street-sweeping practices, or numerous other factors may account for the discrepancies.

Table 4

Metals Concentrations Reported in the Literature*

Study	Lead	Zinc	Copper	Nickel	Chromium	Magnesium	Calcium	Manganese	Iron
(Wilber and Hunter, 1979)									
Saddle River, NJ									
mean	0.220	0.063	0.021	0.016	0.005	--	--	--	--
range	0.050-0.840	0.018-0.144	0.005-0.054	N.D.-01037	N.D.-0.009	--	--	--	--
Lodi Br., NJ									
mean	0.354	0.132	0.031	0.022	0.194	--	--	--	--
range	0.020-1.03	0.012-0.380	N.D.-0.127	N.D.-0.047	0.020 1.03	--	--	--	--
Lodi, NJ rainfall	0.045	0.040	0.006	0.003	0.001	--	--	--	--
(NEIWPCC, 1979)									
Concord, NH									
Urban runoff	0.74	0.55	--	--	--	--	--	0.13	3.3
mean	0.74	0.55	--	--	--	--	--	0.13	3.3
range	0.05-2.9	0.05-1.2	--	--	--	--	--	0.05-0.55	0.04 18.0
(Black, 1980)									
Upstate NY									
Mall Parking Lot Runoff (range)	0.04-0.39	0.29-3.35	--	--	--	9.9-157.6	136.5-1154.2	0.080 0.04	0.186-6.08
Rainfall (range)	0.04-0.08	0.26-0.29	--	--	--	0.1-33.8	27.3-182	0.01-0.06	0.31-2.04

Table 4 continued

Study	Lead	Zinc	Copper	Nickel	Chromium	Magnesium	Calcium	Manganese	Iron
(Colston, 1974)									
Durham, NC									
Urban runoff	0.46	0.36	0.15	0.15	0.23	10.0	4.8	0.67	12.0
(Betson, 1978)									
Knoxville, TN									
Bulk Precipitation	0.05	--	--	--	--	0.74	3.9	0.05	0.18
Commercial Runoff	0.34	--	--	--	--	5.6	25.0	0.85	35.0
Industrial-Residential Runoff	0.13	--	--	--	--	8.2	41.0	0.44	4.0
Suburban Runoff	0.08	--	--	--	--	1.4	8.0	0.05	1.0

*Concentrations are in mg/l.

Table 5

Metals Loads Reported in the Literature*

Study	Lead	Zinc	Copper	Nickel	Chromium
(Bryan, 1972) Durham, NC Urban runoff	5.1	3.5	2.8	2.1	2.8
(Whipple and Hunter, 1977) Lodi, NJ Urban runoff	4.2	2.2	0.8	0.4	0.2
(Whipple et al., 1978) Saddle River, NJ Commercial/Industrial runoff	8-15	5-7	2-15	0.7-6	0.3-1.7
(Whipple, et al, 1978b) Saddle River, NJ Residential runoff	3.8	2.1	0.7	0.5	0.2
Hightstown, NJ Multi-Family Residential runoff	1.8	3.2	0.8	0.2	0.2
(NHWSPCC, 1979) Concord, NH Urban runoff	2.6	1.9	0.6	0.6	0.6

*Loads are in $lb/mi^2/day$.

Of all the heavy metals that are apt to occur in runoff, lead has received the most attention. The reasons for its being the focus of many heavy metals assessments are twofold: lead is known to have toxic qualities, and is relatively abundant in the urban environment. Studies previously cited have associated lead concentrations with the solids fraction of runoff (Rimer et al., 1978; Collins and Ridgway, 1980). Studies of snow samples by Pierstorff (1978) and Newton et al. (1974) and runoff studies by Bryan (1974) and Helsel et al. (1979) have indicated that lead yield increases with urbanization and traffic flow. Newton et al. noted that, according to an EPA report, the average total load emission from automobiles is .11 grams/mile of travel. However, the values quoted were determined before the use of lead-free gas became widespread.

It can be seen in Table 4 that the lead concentrations reported by various researchers differ considerably between studies. Loads reported are less variable (Table 5) and probably more reliable for comparisons between studies. The highest loads were found in the industrial areas of New Jersey (Wilber and Hunter, 1979), and the lowest loads were from the Twin Rivers multiple housing development. Lead loadings in Concord, New Hampshire, were also relatively low, as were zinc, copper, nickel and chromium loadings.

Additional Parameters

Another component of urban runoff which may contribute to receiving water quality degradation is petroleum and its derivatives. Sources include spills, leaks and disposal of motor vehicle lubricants, antifreeze, and hydraulic fluids. Petroleum hydorcarbons, specifically the polynuclear aromatics, have been shown to be carcinogenic and mutagenic (Heaney et al., 1979).

The presence of significant loads of petroleum-derived hydrocarbons in Philadelphia, Pennsylvania, runoff was reported by Hunter et al. (1979). Flow in the storm drains of a 1420 acre basin was found to contain an average of 3.69 mg/l of total hydrocarbons, corresponding to an annual loading of 22.9 pounds per acre. A significant first flush was observed, with peak concentrations approximately four times greater than the flow weighted means. The fraction of hydrocarbons associated with particulates, as well as the total loading rate, was shown to increase with the amount of runoff. The authors indicated that crankcase oil was probably the primary source of the hydrocarbons.

Another parameter, of specific relavance to the Northeast, is road salt contained in storm runoff. It has been estimated that approximately 70 percent of the road salt used in this country is applied in the Northeast, with season totals as high as 20 tons per lane mile (Hawkins and Judd, 1972). In December of 1969, Hawkins and Judd measured chloride concentrations of 11,000 mg/l in a brook near Syracuse, New York. The high concentrations were attributed directly to road salting. In addition, a residual effect of salt applied during the winter was evidenced in the somewhat lower, but still high, chloride concentrations measured during the following summer.

Chloride concentrations in runoff from an urban basin in Concord, New Hampshire, ranged from 2.3 to 62 mg/l, with a flow weighted mean of 12 mg/l. Similarly, Weibel et al. (1966) and Bryan (1972) reported urban runoff mean chloride concentrations of 19.9 and 12.5 mg/l respectively. Although these values are all considerably less than those reported by Hawkins and Judd (1972), it should be noted that these studies, as most runoff studies, were conducted during the warmer months of the year when only the residual effects of road salting would be in evidence. Specific snowmelt sampling might indicate higher chloride concentrations.

Summary

It is evident from this review that storm runoff, especially from urbanized areas, is generally contaminated. The most significant pollutants contained in urban runoff appear to be oxygen-demanding organics and suspended solids, though phosphorus and nitrogen, certain heavy metals (especially lead), and pathogenic bacteria may also be present in sufficient quantities to create a detrimental impact on the receiving water body. It appears to be a common conclusion that the majority of the pollutants (or at least the most significant ones) in urban runoff are associated with suspended solids.

A number of relationships have been proposed as to which factors determine the quality of runoff from an urban area, and to what extent. The general consensus is that land use, percent impervious cover, storm characteristics, and time since the streets were last cleaned (by sweeping or runoff) are the primary variables concerning runoff quality.

The actual quantities of pollutants reported in different studies appear to be quite site-specific, due to the variations in the independent variables, sampling methodology, and fromat of reporting results.

Generally, loading rates are more easily compared between studies than concentrations, because they incorporate primary basin characteristics.

Although it may be concluded that urban storm runoff is typically polluted, the impact that it has on receiving water bodies still remains to be adequately defined. Evaluation of water quality impairment can only be made in light of the potential uses of the specific receiving water body. Heaney et al. (1979), for purposes of comparing studies at the regulatory level (EPA), defined impact as "...loss of beneficial use." Beneficial uses are those such as drinking water supply, swimming, and recreation, which are listed as federal, state and local water laws. Heaney et al. cite two general types of impacts which might occur from storm runoff. The event-type are short-term impacts such as fish kills and temporary beach closings. Trend-type impacts are more long-term, and include loss of species diversity and general biological deterioration.

As a result of a comprehensive examination of all urban runoff literature and unpublished sources, Heaney et al. found that documented cases of such impacts are very scarce. Although it was determined that approximately 75 percent of the runoff studied goes to rivers, 5 percent to lakes and 20 percent to estuaries or oceans, they emphasize that in most cases, these are not the primary receiving waters. Instead, urban streams are the first to receive most of the runoff, and they are often grossly polluted from other sources already. Generally, there have been few fish kills reportedly resulting from urban runoff pollution, but Heaney et al. do cite it as the major source of the coliform counts which force beach closings.

It appears that in order for efficient stormwater management to occur, accurate evaluations of existing impacts must first be made. This requires not only characterization of runoff quality, but also its effects on the receiving stream. Where beneficial use impairment is shown to occur, effective control measures should then be implemented. However, in order to design such control measures, it is first necessary to identify the major sources of runoff pollution and delineate the variables which affect runoff.

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